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THE SUBSTITUTION OF IVD ALUMINUM FOR CADMIUM

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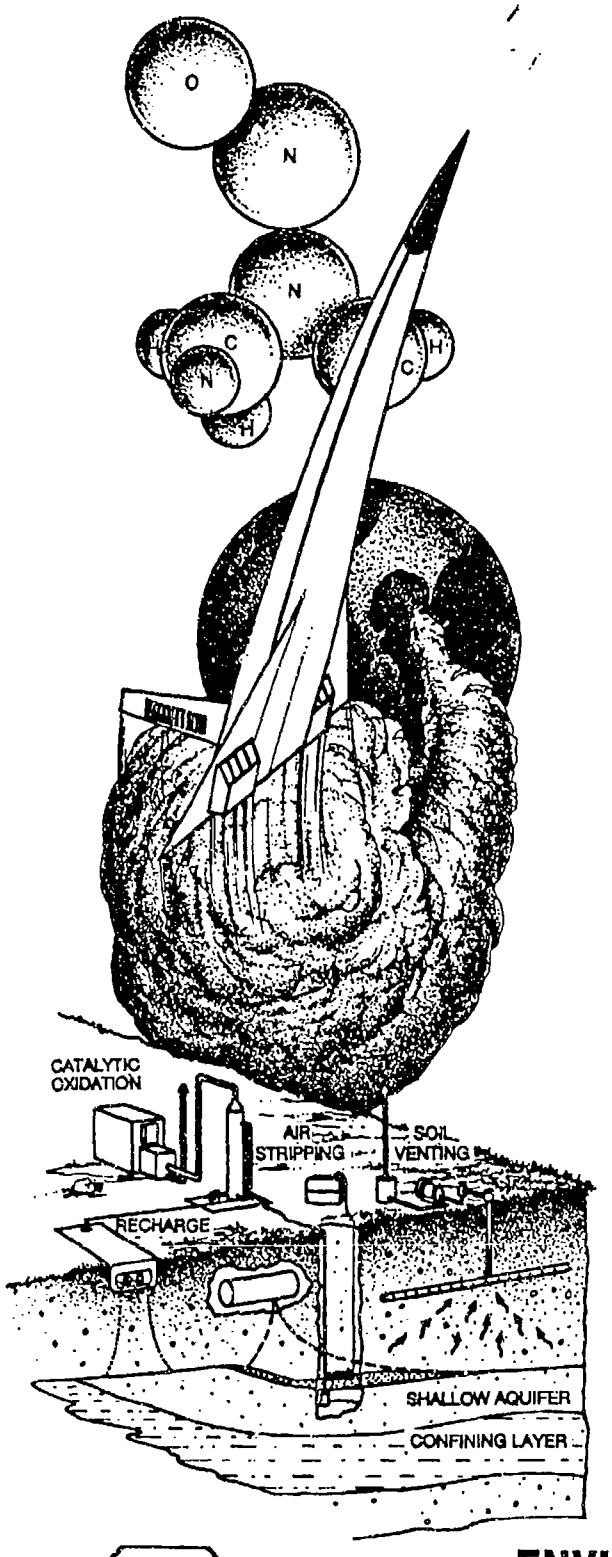

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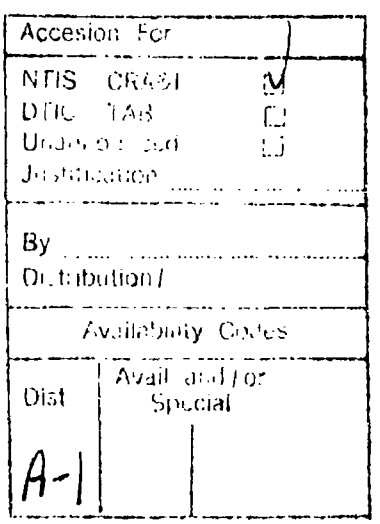

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The U.S. Air Force is concerned about the use of toxic processing at the Air Logistics Centers (ALCs). As part of their task to reduce hazardous waste production, they contracted the McDonnell Aircraft Division (MCAIR) of McDonnell Douglas through EG&G, Idaho to demonstrate that IVD aluminum coating can replace the various cadmium processes across-the-board at the ALCs. The IVD aluminum coating and process are environmentally clean and produce no hazardous waste. Both cadmium and the cadmium processes involving electroplating are toxic and require hazardous waste disposal.

In Phase I of this contract, technical information providing a comprehensive comparison between IVD aluminum and cadmium processing was compiled into a data base handbook for use by ALC personnel. Also in Phase I, MCAIR determined that IVD aluminum could replace cadmium processing without concern for about 80 percent of the ALC parts.

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EXECUTIVE SUMMARY

During the period of 15 April 1989 to 18 May 1990, McDonnell Aircraft Company (MCAIR) completed Phase II of the three-phase program to demonstrate that Ion Vapor Deposited (IVD) aluminum coating can replace toxic cadmium processing at the Air Logistics Centers (ALCs). A demonstration of the IVD aluminum process will be conducted at the Warner Robins (WR) ALC during Phase III. This phase will demonstrate the applicability of IVD aluminum as a replacement for cadmium for detail parts that are now processed with cadmium at WR.

Phase I of the program compiled data comparing the IVD aluminum process to the various cadmium processes into a data base handbook. It included a review of aircraft parts now processed with cadmium at the five ALCs to identify parts for which IVD aluminum can immediately replace cadmium without concern. Parts which exhibit "areas of concern" were also identified. Phase II focused on addressing "areas of concern". These are ALC applications where either IVD aluminum by itself is not an adequate replacement for cadmium or insufficient data exists. They included coverage of internal surfaces, lubricity, and to a lesser extent, erosion resistance.

During Phase II, MCAIR demonstrated the effectiveness of both sacraficial-type and barrier-type supplemental protection systems for internal surfaces. Torque-tension data was generated for ALC applications involving threaded ngine hardware and wheel tie-bolts that demonstrates the acceptability of the use of IVD aluminum with proper lubrication. MCAIR suggests that a thicker IVD aluminum coating be used where feasible for erosive applications. Where thickness tolerance is critical, MCAIR demonstrated improved erosion resistance with the use of an aluminum-alloy evaporant containing 12 percent silicon.

MCAIR also supported the procurement and acceptance of a state-of-the-art IVD aluminum coater for the WR-ALC during Phase II. MCAIR prepared the procurement specification, conducted preliminary acceptance testing of the coater at a subcontractor site and final acceptance testing at WR, and trained WR personnel. MCAIR also designed and procured a fixture to hold and mask a

PREFACE

This report was prepared by McDonnell Douglas Aircraft Company, P.O. Box 516, St. Louis, MO 63166-0516, EPA Contract C87-101602, "The Substitution of Ion Vapor Deposited (IVD) Aluminum for Cadmium." The work was done for the Air Force Engineering and Services Laboratory, Tyndall Air Force Base, Florida 32403-5319.

This final report describes the methods used, and the results of the analysis of the Ion Vapor Deposition (IVD) metal plating technique. This technology can save the Air Force millions of dollars in the cost of hazardous waste disposal due to the reduction in the usage of cadmium.

This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

The work was performed between 15 April 1989 to 19 May 1990. The project officer was Lt Phil Brown.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this program is to verify the applicability of Ion-Vapor-Deposited (IVD) aluminum as a replacement for cadmium processing at the Air Force Air Logistics Centers (ALCs). Whereas cadmium has been widely used as a corrosion-resistant finish on steel, the substitution with IVD aluminum provides acceptable or improved performance in virtually all applications. More importantly, the substitution will make a major contribution to reducing hazardous waste production and its associated adverse effect on the environment.

B. BACKGROUND

Both the aluminum coating and the IVD process are environmentally clean. Cadmium, on the other hand, is a heavy metal and is toxic to humans. Once it escapes into the environment, it can find its way into the water supply or food chain. Also, with electroplated cadmium processing, there are additional hazards associated with cyanide products in the plating bath. On the economic side, a suitable replacement can both reduce life-cycle costs and provide an immediate return on investment by eliminating costs associated with control technology required to meet ratcheting environmental regulations and with hazardous waste collection, storage, and disposal.

There are inherent advantages to the substitution of IVD aluminum for cadmium, in addition to hazardous waste reduction. IVD aluminum outperforms cadmium in preventing corrosion in acidic environments and actual service tests. Also, aluminum coatings can be used at temperatures up to 950°F, whereas cadmium is limited to 450°F. IVD aluminum coatings can be applied to high-strength steel without fear of hydrogen embrittlement. Aluminum coatings can be used in contact with titanium without causing solid metal embrittlement, and they can also be used in contact with fuels; cadmium is

prohibited for these applications. Additionally, IVD aluminum can be used in space applications, whereas cadmium is limited because of sublimation.

The coating requirements for IVD aluminum are specified in MIL-C-83488, the tri-service specification for pure aluminum coatings. After coating, the parts are generally chromate-treated in accordance with MIL-C-5541. This provides additional protection against corrosion, forms a good base for paint adhesion, and is a common treatment for aluminum alloy surfaces. In virtually all applications, IVD aluminum can replace cadmium of equal thicknesses. It can also be applied thicker than cadmium where part tolerance permits; this results in additional corrosion resistance.

The Air Force Environmental Services Center (AFESC) has contracted the McDonnell Aircraft Company (MCAIR) through EG&G, Idaho to demonstrate that IVD aluminum can replace cadmium across-the-board at the ALCs. The thrust of the program is to reduce hazardous waste production. This report addresses Phase II of a three-phase program. The phases are:

Phase I - Data Compilation and Process Evaluation

Phase II - Procurement and Research & Development

Phase III - Demonstration

In Phase I, the technical information providing a comprehensive comparison of the performance of IVD aluminum and the performance of the cadmium processes was compiled. This provided the designer with a readily accessible technical database (Reference 1) to justify the substitution of IVD aluminum for cadmium for about eighty percent of the current ALC applications. This report addresses the other 20 percent of the applications which have been identified as "areas of concern" for eliminating cadmium by the ALCs. These included coverage of internal surfaces, improved lubricity, and to a lesser extent, improved erosion resistance.

C. SCOPE/APPROACH

Phase II activities also included procurement support of an IVD aluminum coater to assure that the Phase III demonstration will be conducted in a state-of-the-art system. The related MCAIR activity is discussed in Section II.

In some cases, the "areas of concern" resulted from a lack of sufficient data. Other areas required the development of supplemental processing to be used in conjuction with the IVD aluminum coating. The approaches used to address the three individual "areas of concern" are presented in Sections III, IV, and V.

The performance of barrier-type and sacraficial-type supplemental protection systems applied to internal surfaces was tested. Data comparing the effect of various bolt finish - nut finish - lubricant combinations on torque-tension was also generated. The erosion resistance of IVD aluminum to diffused nickel-cadmium was compared, and the effect of supplemental topcoats and different IVD aluminum-alloy evaporants were evaluated.

Finally, a "hands-on" approach that MCAIR has proposed for the Phase III demonstration is presented in Section VII.

SECTION II

IVD ALUMINUM COATER PROCUREMENT SUPPORT

A. PROCUREMENT SPECIFICATION

The IVD aluminum coating is applied in production coating equipment called Ivadizers®. The basic equipment consists of a steel vacuum chamber, a pumping system, fixturing to hold the parts, an evaporator power supply, and a high-voltage power supply (Figure 1).

The IVD processing sequence consists of pumping the vacuum chamber down to about 10^{-4} Torr. The chamber is then backfilled with argon gas to about 10 microns, and a high negative potential is applied between the parts being coated and the evaporation source. The argon gas becomes ionized and creates a glow discharge around the parts. The positively charged gas ions bombard the negatively charged surface of the parts and performs a final cleaning, which contributes to good coating adhesion.

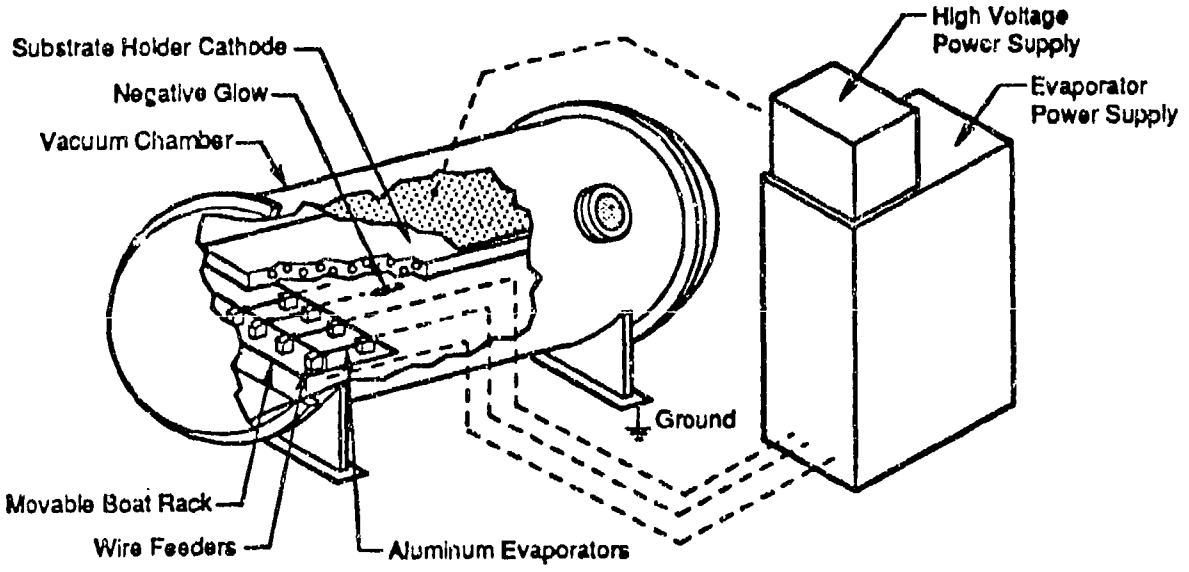


Figure 1. Schematic of an Ion Vapor Deposition System

Following glow discharge cleaning, aluminum wire is evaporated by being continuously fed into resistance-heated crucibles. As the aluminum vapor passes through the glow discharge, a portion of it becomes ionized. This, in addition to collision with the ionized argon gas, accelerates the aluminum vapor toward the part surface, resulting in excellent coating adhesion and uniformity.

Coater productivity and reliability have been continuously improved since the first unit was installed at the Navy Overhaul Facility at North Island in 1974. There are now approximately 70 Ivadizers® in service around the world which primarily serve the aerospace market.

Phase III of the program requires substituting IVD aluminum for cadmium processing for those detail parts that are now protected with cadmium at the WR-ALC. Accordingly, MCAIR prepared a procurement specification (Reference 2) for the coating system to be used for the Phase III demonstration. This document was used as the basis for the procurement of a state-of-the-art coater from Abar-Ipsen Industries.

The WR coating system includes several items that are designed to improve productivity. They include:

- Parts-holding fixtures designed for: larger parts that are hung stationary while being coated; larger parts that are rotated while being coated; and small parts that are rotated in barrels while being coated.

- A fixture designed (Reference 3) and fabricated by MCAIR for the C-130 Barrel Hub. It will be used in conjunction with the rotary parts holding rack to both hold the barrel hub and mask areas of the hub which are not to be coated. The fixture will be used to demonstrate improved productivity levels. MCAIR projects that eight barrel hubs can be processed in a 90-minute-coating cycle with additional fixtures of this nature.

o Additional pumping capability that basically reduces the pumpdown portion of the IVD aluminum coating cycle by 50 percent or more. A cyropump system will be used in conjunction with the conventional mechanical and diffusion pumping systems. MCAIR has demonstrated that cyropumping efficiently removes water vapor during pumpdown. This benefit is particularly effective when the combination of aluminum buildup in the coating chamber and humid weather conditions often result in pumpdown times of over one hour. The cyropump system will not only reduce pumpdown time to 30 minutes or less under these conditions but will also enable less frequent "cleaning" of the coater to remove aluminum buildup.

MCAIR also included a comprehensive list of spare parts to be procured along with the coater (Reference 2). These spare parts are considered to be adequate to prevent any coater inactivity due to replacement part procurement delays.

Copies of the Reference 2 Procurement Specification and the Reference 3 Fixture Design are available from either WR-ALC/MANEE, W. E. Elmore or MCAIR-Dept. 357, V. L. Holmes.

B. ACCEPTANCE TESTING

MCAIR performed the final acceptance test of the IVD aluminum coater and its associated systems after their installation at the WR-ALC. The tests were designed to demonstrate compliance with the requirements stipulated in Reference 2 and in MIL-C-83488. Final acceptance was based on the following testing:

o Safety - MCAIR simulated failure to demonstrate the proper operation of all safety devices and controls.

o Coating Appearance - The IVD aluminum coating was verified to be smooth, fine grained, adherent, uniform in appearance, free from pits, burning, porosity, and other defects. The coating showed no indication of contamination or improper operation of equipment, such as excessively powdered or darkened coatings. Slight discoloration of the coating on test coupons was

removable by glass bead peening. Parts chromated per MIL-C-5541 had a continuous, distinctly colored protective film ranging in color from yellow to iridescent bronze.

o Adhesion - The adhesion of the coating to one-inch by four-inch by 0.040-inch alloy steel test strips was verified by the following tests:

- Scraping Test - The surface of the coated article was scraped to expose the basic metal. An examination of the surface at four diameters magnification showed no evidence of nonadhesion.

- Bend-to-Break Test - Test strips were clamped in a vise and bent back and forth until strip rupture occurred. An examination of the coating along the break-line at four diameters magnification showed no evidence of non-adhesion.

- Glass Bead Peening Test - The coating test showed no sign of separation from the base metal when glass bead peened with size 10 glass beads at an operating pressure of 40 psig. This test was performed by slowly fanning the peener nozzle over the test strips at a distance of 6 to 8 inches.

o Corrosion Resistance Testing - MCAIR tested the corrosion resistance of alloy steel panels coated with the various thickness classes defined in MIL-C-83488C in a five-percent neutral salt fog environment per ASTM Method B-117. Type II (chromated) parts coated with Class 1, 2, and 3 coatings showed no evidence of corrosion of the basis metal when exposed for 672, 504, and 336 hours, respectively.

o Reliability Test - The reliability of the IVD aluminum coater was demonstrated by performing ten continuous coating cycles without failure of the system. Coating adhesion as described above was verified after each coating cycle.

o Vacuum Level Test - The coater's pumping system was verified to evacuate a clean, dry chamber to 9×10^{-5} torr within 1 hour without cryopump engagement and within 30 minutes with cryopump engagement.

o Pressure Levels - Base pressure and time in minutes to reach operating pressures for a clean, dry chamber with and without the cryopump engaged were established for the following system components: the roughing pump/blower; the diffusion pump; and the holding pump.

C. PERSONNEL TRAINING

MCAIR provided training at WR for electronic engineers, electrical maintenance technicians, and electronic maintenance technicians which included the following:

o Review of electrical and electronic systems, including wiring diagrams and drawings

o Troubleshooting procedures for the current sources and control systems

o Electrical and electronic equipment servicing and care

o Adjustment procedures (locating components, adjustments to be made, values to be measured, equipment required for making adjustments)

o Applicable circuit board repair procedures

o Recommended motor, switch, relay, solenoid, etc., maintenance servicing and repair

MCAIR also provided training at WR for operators, mechanical maintenance technicians, and mechanical engineering technicians which included the follow:

o A review of mechanical diagrams and drawings

o Component location and function

- Troubleshooting procedures and techniques
- Repair procedures
- Assembly/disassembly procedures
- Adjustments - (how, when and where)
- Preventive maintenance procedures
- Valve location and functions
- Valve adjustment and maintenance procedures
- System operation
- Potential operation problems
- Potential maintenance problems

Personnel from the Ogden (OO) ALC also attended the WR training sessions.

SECTION III

COVERAGE OF INTERNAL SURFACES

A. PROBLEM

Although the IVD aluminum process is not confined to line-of-sight application, it does have limitations regarding the ability to coat into deep recesses. Generally speaking, the process can be used effectively to coat into a bore or recess for a distance equal to approximately one times the diameter of the opening. Therefore, for parts with a length-to-diameter ratio greater than 1:1 (or 2:1 if open at both ends), the IVD aluminum coating coverage on portions of the internal surface may be inadequate. For example, the internal surface of the Figure 2 cylinder which is 4-inches in diameter and 18-inches long and open at both ends would be coated effectively for approximately 4-inches from both ends. The remaining 10-inches of internal surface in the middle of the cylinder would have a thin coating to no coating at all.

Even though techniques may be developed to evaporate aluminum within deep recesses using an internal anode, this procedure could be prohibitively expensive for most applications. Therefore, IVD aluminum by itself cannot be a direct cadmium substitute for some ALC parts, such as landing gear details and turbine shafts, because of internal surface protection requirements. However, there are protection systems that are compatible with IVD aluminum and may qualify as alternatives to cadmium for internal surfaces. Supporting data for such qualification, however, needs to be developed.

B. SOLUTION/APPROACH

Combine IVD aluminum with supplemental protection systems to provide complete coverage of internal surfaces. Candidate protection systems are shown in Table 1 and include:

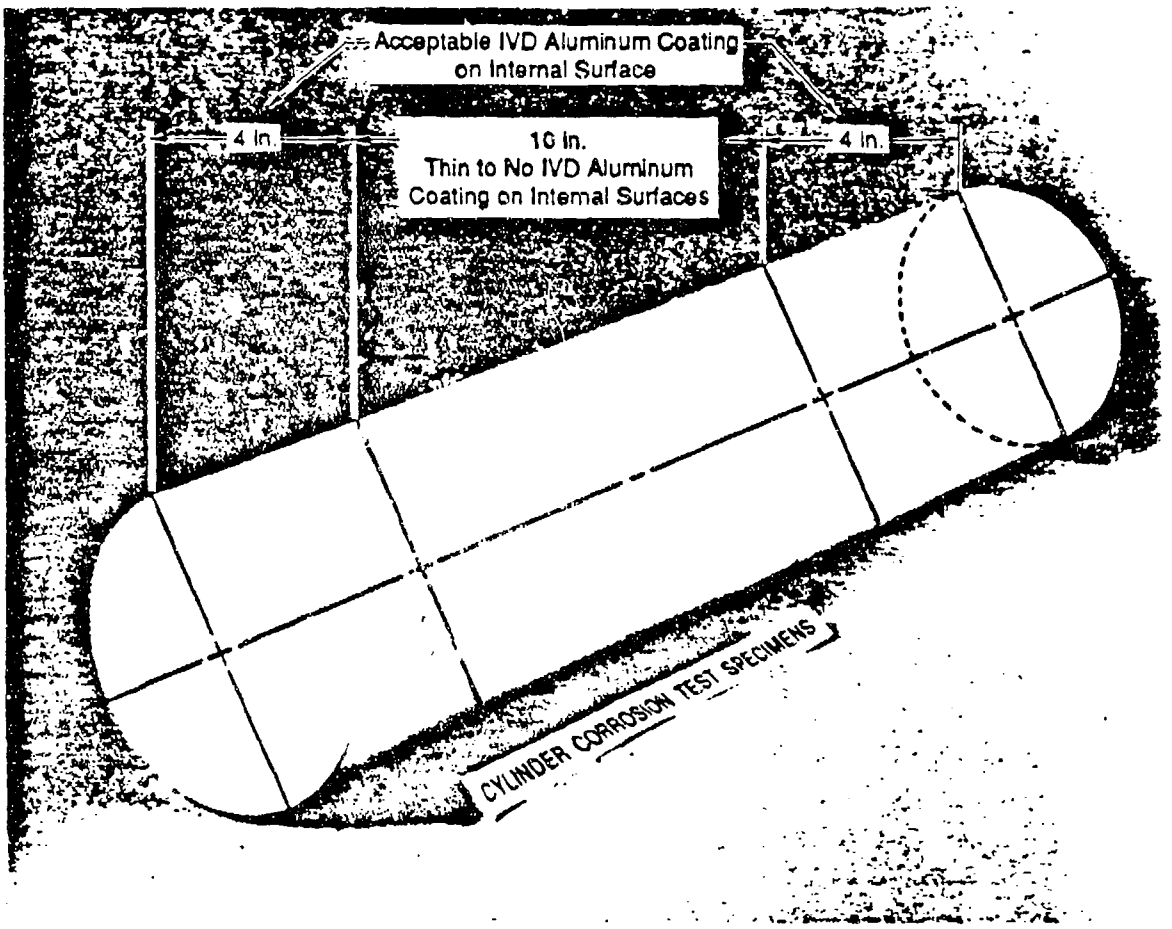


Figure 2. IVD Aluminum Coated 4-Inch Diameter by 18-Inch Long Cylinder

o Aluminum-filled MIL-C-81751 basecoats - These are aluminum-filled paint-type materials currently in use by the ALCs. The coatings can be brush- or spray-applied to internal surfaces. The coating becomes electrically conductive when either cured at high temperature or burnished with glass beads. The electrically conductive coating provides sacrificial corrosion-resistance protection to alloy steel substrates. Alseal®, Sermetel®, and Xylar® are tradenames of available aluminum-filled coatings suitable for this application.

o Primer, topcoats, and sealants - Combinations of various primers, topcoats, and sealants have shown promise in preliminary testing and may afford acceptable barrier-type corrosion resistance protection to internal surfaces. Standard materials in use by the ALCs like epoxy primers, polyurethane topcoats, and sprayable sealants are candidates.

TABLE 1. CANDIDATE INTERNAL SURFACE PROTECTION SYSTEMS APPLIED TO PANELS.

Supplemental Protection System Material Identification[a]	Applicable Mil-Specs[b]	Protection Type	Processor[a]
Coatings for Industry: Alseal 518	MIL-C-81751	Sacrificial	MCAIR
Whitford: Xylar I	MIL-C-81751	Sacrificial	MCAIR
Sermatech: Sermetel CR984-LT	MIL-C-81751	Sacrificial	Sermatech
Epoxy Primer Polysulfide Sealant Polyurethane Topcoat	MIL-P-23377 MIL-S-83430 MIL-C-83286	Barrier[c] Barrier Barrier	MCAIR
MCAIR: Epoxy Primer Polysulfide Sealant (Fill and Drain)	None MIL-S-83430	Barrier[c] Barrier	MCAIR
Whitford: P-92 Primer Whitford: Xylan 1014 Topcoat	None None	Barrier Barrier	MCAIR
Whitford: P-92 Primer Whitford: Xylan 1010 Topcoat	None None	Barrier Barrier	MCAIR
Waterborne Epoxy Primer Polysulfide Sealant	MIL-P-85582 MIL-S-83430	Barrier[c] Barrier	MCAIR
Zinc Phosphate MCAIR: Epoxy Primer Polyurethane Topcoat	MIL-P-16232 None MIL-C-83286	Barrier Barrier[c] Barrier	Embee Plating
MCAIR: Epoxy Primer DeSoto: Epoxy Powder Coating	None None	Barrier[c] Barrier	DeSoto
Waterborne Epoxy Primer DeSoto: Epoxy Powder Coating	MIL-P-85582 None	Barrier[c] Barrier	DeSoto
NADC Unicoat DeSoto: Epoxy Powder Coating	None None	Barrier[c] Barrier	DeSoto
DeSoto: Epoxy Powder Coating	None	Barrier	DeSoto

TABLE 1. CANDIDATE INTERNAL SURFACE PROTECTION SYSTEMS APPLIED TO PANELS (CONCLUDED).

Supplemental Protection System Material Identification[a]	Applicable Mil-Specs[b]	Protection Type	Processor[e]
Zinc Phosphate	MIL-P-16232	Barrier	Sunbelt Coating
Whitford: P-92 Primer	None	Barrier	
Whitford: Xylan 1014 Topcoat	None	Barrier	
Zinc Phosphate	MIL-P-16232	Barrier	Sunbelt Coating
Whitford: Xylan 5611 Primed[d]	None	Barrier[c]	
Whitford: Xylan 5251 Topcoat	None	Barrier	
Manganese Phosphate	MIL-P-16232	Barrier	Embee Plating
Waterborne Epoxy Primer	MIL-C-85582	Barrier[c]	MCAIR
High-Solids Polyurethane Topcoat	MIL-P-85285	Barrier	Embee Plating

a Suppliers:
- Coatings for Industry, Inc.; 319 Township Line Road, Souderton, PA 18964, (215) 723-0919
- Whitford Corporation; Box 507, West Chester, PA 19381, (215) 296-3200
- Sermatech International, Inc.; 155 South Limerick Road, Limerick, PA 19468, (215) 948-5100
- Naval Air Development Center; Warminster, PA 18974

b Military Specifications:
- MIL-P-16232 Phosphate Coating, Heavy, Manganese or Zinc Base (for Ferrous Metals)
- MIL-P-23377 Primer Coating, Epoxy Polyamide, Chemical and Solvent Resistant
- MIL-C-81751 Coating, Metallic Ceramic
- MIL-C-83286 Coating, Urethane, Aliphatic Isocyanate, for Aerospace Applications
- MIL-C-83430 Sealing Compound, Integral Fuel Tank and Fuel Cell Cavities, Intermittent Use to 360°F (182°C)
- MIL-C-85285 Coating: Polyurethane, High-Solids
- MIL-P-85582 Primer Coatings: Epoxy, VOC Compliant, Chemical Solvent Resistant

c Although these materials are designated barrier, they do contain leachable compounds which provide sacrificial protection.

d Zinc Rich, May Provide Some Sacraficial Protection.

e Processors:
- McDonnell Aircraft Company (MCAIR); P.O. Box 516, St. Louis, MO 63166 (314) 233-8663
- Sermatech International, Inc.; 155 South Limerick Road, PA 19468, (215) 948-5100
- Embee Plating; 2136 South Hathaway, Santa Ana, CA 92705 (714) 546-9842
- DeSoto, Inc.; Box 5030, Des Plaines, IL 60017, (312) 391-9365
- Sunbelt Coating Company, Inc.; 1805 West Detroit Street, Broken Arrow, OK 74012, (918) 258-8007

Screen candidate protection systems applied to alloy steel test panels by testing for adhesion, coverage and uniformity, and corrosion resistance. Apply selective protection systems which pass the screening tests to the internal surface of cylindrical details representing actual ALC parts. Process the cylinders in the following sequence:

a. Coat the cylinders with IVD aluminum for external coverage and transitional coverage into the bore of the cylinder.

b. Brush, spray, or "fill & drain" apply protection systems onto the internal surface of the cylinders covering both bare areas and areas coated with IVD aluminum.

c. Section the cylinders lengthwise to expose internal surfaces.

d. Test the adhesion, coverage and uniformity, and corrosion resistance of the protection systems on the exposed internal surfaces.

C. TEST DATA

1. Test Panels

Eighty 4-inch by 6-inch 4130 alloy steel panels were processed with candidate internal surface protection systems. Forty percent of the test panels were left bare. The other sixty percent were first coated with a thin coating (less than 0.0003 inch) of IVD aluminum per MIL-C-83488. These panels simulate internal surface areas coated with less than the minimum acceptable amount of IVD aluminum where the coating transitions from an acceptable thickness to no coating at all. Three different conditions of thin IVD aluminum coatings were evaluated after being overcoated. They are:

- As coated (not peened) and not chromated (Type I)

- o Peened, but not chromated (Type I)

- o Peened and chromated (Type II)

The peened and chromated condition is the normal processing mode for IVD aluminum coating. The other two conditions were evaluated for possible benefits in relation to the standard mode when overcoated with the candidate protection systems. One panel of each of the IVD aluminum coating conditions was overcoated with each candidate protection system. In addition, two bare steel panels were processed with each candidate protection system to simulate internal surfaces coated with a trace to no IVD aluminum. A typical test panel set processed with Table I candidate protection systems is shown in Figure 3.

a. Processing Parameters - All of the steel test panels were cleaned using the normal procedures for precleaning alloy steel substrates for IVD aluminum processing. This entails solvent vapor degreasing followed by mechanical grit blasting with #220 aluminum oxide grit at 60 psi. The subsequent processing parameters for each candidate protection system such as application method, number of coats, thickness, and cure time/temperature are given in Table 2.

b. Thickness/Uniformity - Thicknesses were measured with a Magne-Gage at three points across the six-inch length of the panel. The approximate thickness of each protection system component material is shown in Table 2. The total protection system thickness and uniformity is shown in Table 3.

c. Coating System Adhesion - The adhesion of the candidate coating systems was tested as follows:

- o The test panel was cleaned with solvent and wiped dry with clean cheesecloth before solvent evaporation.

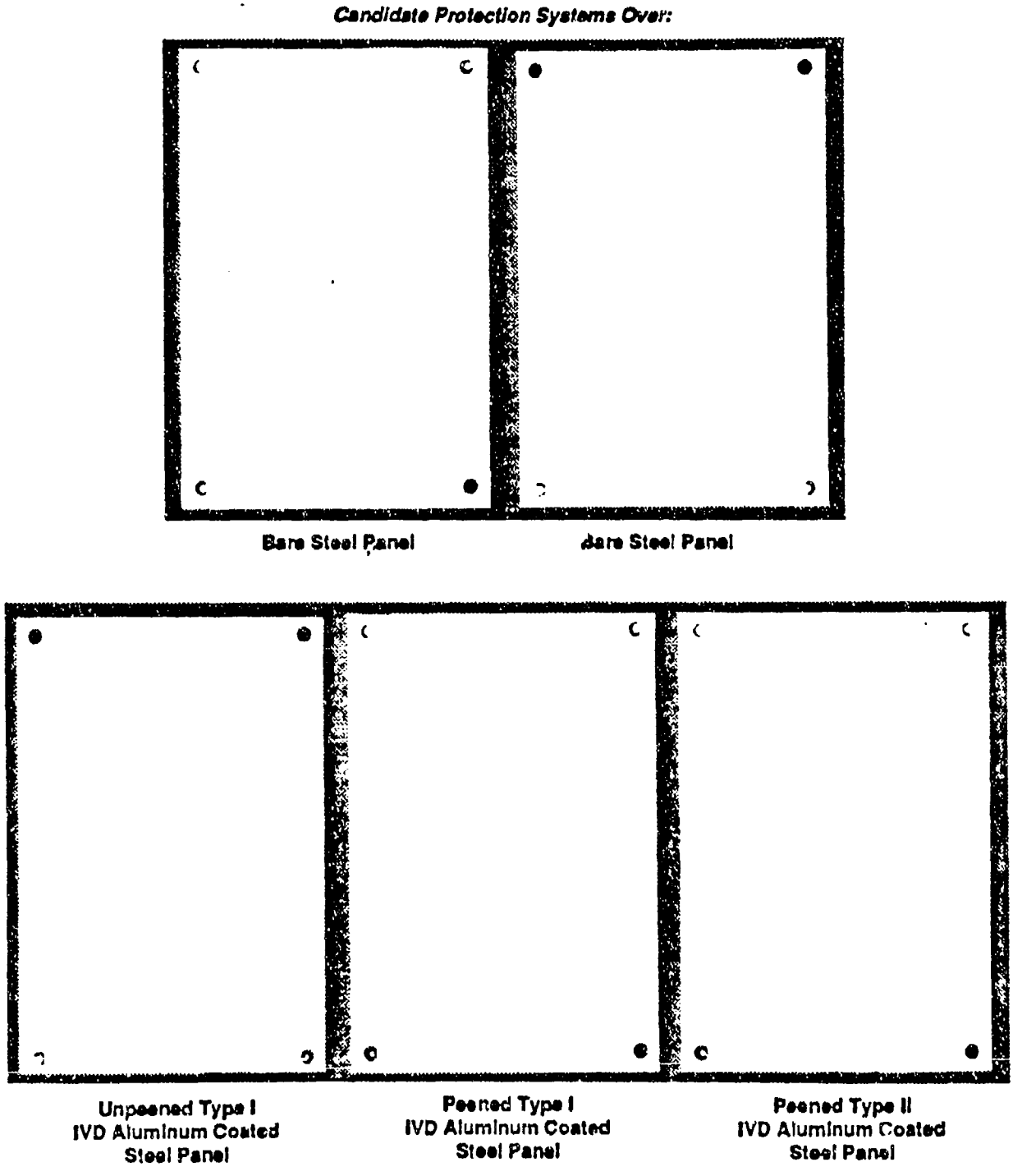


Figure 3. Typical 4-inch by 6-inch 4130 Alloy Steel Test Panel Set Processed With Candidate Internal Surface Protection Systems.

TABLE 2. PROCESSING PROCEDURES FOR CANDIDATE PROTECTION SYSTEMS APPLIED TO PANELS.

Protection System Components	Application Method	Number of Coats	Approximate Component Thickness (in.) Per Coat	Cure Time/Temperature
Coatings for Industry: Alseal 518	Spray	2	0.0015	60 min @ 500°F
Whitford: Xylar 1	Spray	2	0.0015	200 min @ 500°F
Sermatech: Sermetel CR984-LT	Spray	2	0.0008	60 min @ 375°F
Epoxy Primer	Spray	2	0.0070	60 min @ Room Temp
Polysulfide Sealant	Brush	1	0.0015	45 min @ 160°F
Polyurethane Topcoat	Spray	2	0.0015	60 min @ 170°F
Epoxy Primer	Fill and Drain	1	0.0010	30 min @ 160°F
Polysulfide Sealant	Fill and Drain	1	0.0160	180 min @ 160°F
Whitford: P-92 Primer	Spray	2	0.0003	10 min @ 350°F
Whitford: Xylan 1014 Topcoat	Spray	2	0.0003	10 min @ 450°F
Whitford: P-92 Primer	Spray	2	0.0004	10 min @ 350°F
Whitford: Xylan 1010 Topcoat	Spray	2	0.0004	10 min @ 450°F
Waterborne Epoxy Primer	Spray	1	0.0010	30 min @ 160°F
Polysulfide Sealant	Spray	2	0.0015	180 min @ 160°F
Zinc Phosphate	Tank Immersion	1	0.0005	Not Required
Epoxy Primer	Spray	1	0.0010	60 min @ Room Temp
Polyurethane Topcoat	Spray	2	0.0015	30 min @ 200°F
Epoxy Primer	Spray	1	0.0010	60 min @ Room Temp
Epoxy Powder Coating	Spray	1	0.0030	15 min @ 250°F
Waterborne Epoxy Primer	Spray	1	0.0010	60 min @ Room Temp
Epoxy Powder Coating	Spray	1	0.0030	15 min @ 250°F
NADC Unicoat	Spray	1	0.0050	60 min @ Room Temp
Epoxy Powder Coating	Spray	1	0.0030	15 min @ 250°F
Epoxy Powder Coating	Spray	1	0.0030	15 min @ 250°F
Zinc Phosphate	Tank Immersion	1	0.0002	Not Required
Whitford: P-92 Primer	Spray	1	0.0002	10 min @ 350°F
Whitford: Xylan 1014 Topcoat	Spray	2	0.0002	10 min @ 450°F
Zinc Phosphate	Tank Immersion	1	0.0001	Not Required
Whitford: Xylan 5611 Primer	Spray	1	0.0010	10 min @ 400°F
Whitford: Xylan 5251	Spray	1	0.0010	10 min @ 400°F
Manganese Phosphate	Tank Immersion	1	0.0005	Not Required
Waterborne Epoxy Primer	Spray	1	0.0010	30 min @ 160°F
High-Solids Polyurethane Topcoat	Spray	2	0.0010	30 min @ 160°F

TABLE 3. UNIFORMITY AND AVERAGE THICKNESS OF CANDIDATE PROTECTION SYSTEMS.

Processor: Protection System	Protection Thickness (mils)			Average Thickness (mils)
	A	B	C	
MCAIR: Alseal 518	3.0	3.0	2.9	3.0
MCAIR: Xylar I	3.3	3.4	3.6	3.4
Sermatech: Sermetal CR984-LT	1.5	1.6	1.6	1.6
MCAIR: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat	5.5	5.6	5.9	5.7
MCAIR: Epoxy Primer, Polysulfide Sealant (Fill and Drain)	11.5	10.3	13.5	11.8
MCAIR: P-92 Primer, Xylan 1014 Topcoat	1.3	1.3	1.3	1.3
MCAIR: P-92 Primer, Xylan 1010 Topcoat	1.7	1.7	1.7	1.7
MCAIR: Waterborne Epoxy Primer, Polysulfide Sealant	4.6	4.9	4.8	4.8
Embee Plating: Zinc Phosphate, Epoxy Primer, Polyurethane Topcoat	4.3	4.3	4.3	4.3
DeSoto: Epoxy Primer, Epoxy Powder Coating	4.8	4.7	4.2	4.6
DeSoto: Waterborne Epoxy Primer, Epoxy Powder Coating	4.4	4.2	4.0	4.2
DeSoto: NADC Unicoat, Epoxy Powder Coating	7.5	7.8	8.1	7.8
DeSoto: Epoxy Powder Coating	3.9	3.1	2.8	3.3
Sunbelt Coating: Zinc Phosphate, P-92 Primer, Xylan 1014 Topcoat	0.8	0.7	0.8	0.8
Sunbelt Coating: Zinc Phosphate, Xylan 5611 Primer, Xylan 5251 Topcoat	1.3	1.3	1.4	1.3
MCAIR: Manganese Phosphate, Waterborne Epoxy Primer, High-Solids Polyurethane Topcoat	3.2	2.8	2.7	2.9

o A dry tape adhesion test using 3M Company #250 tape was conducted by placing a one-inch wide strip of the tape across the panel pressing the tape down with firm hand pressure against the panel, lifting the loose end of the tape to an angle of 45 degrees to the panel, and removing the tape from the panel with one, abrupt motion.

o A 4- by 4- by 1/8-inch pad of cheesecloth saturated with tap water was covered with polyethylene film and taped against the panel for 24 hours.

o After 24 hours, the pad was removed and the panel was wiped dry with clean cheesecloth.

o The tape test was repeated within 2 minutes after removal of the water-soaked pad.

All of the candidate protection systems passed the dry tape and wet tape adhesion tests.

d. Corrosion Resistance - The corrosion resistance requirement for the candidate internal surface protection systems was established as 672 hours in a five-percent neutral salt fog environment per ASTM B-117. This is the same requirement that MIL-C-83488 invokes on a Class 1, Type II IVD aluminum coating. There are three classes and two types of coatings. Class 1 coatings are the thickest and are generally used because they provide the best corrosion resistance. Class 2 and 3 coatings are thinner and are generally used for parts with tolerance limitations such as fastener threads. Type I does not receive supplementary chemical processing. Type II has a supplementary chromate treatment in accordance with MIL-C-5541. Type II coatings are usually recommended because the chromate conversion coating provides additional corrosion protection and promotes better adhesion of most paint-type topcoats.

The majority of the 16 candidate protection systems applied over bare steel panels not only met but far surpassed the minimum 672 hour corrosion resistance requirement. All of the protection systems applied over a thin IVD aluminum coating (less than 0.0003 inch) met the minimum 672 hour requirement. Minimum corrosion resistance acceptance as well as corrosion resistance duration of the candidate protection systems are shown in Table 4.

Figures 4 through 17 show the protection systems applied to bare (no IVD aluminum) 4-inch by 6-inch alloy steel test panels that met the minimum requirement. Exposure times of 672 hours, 1344 hours, and longer are shown for most of the panels. The panels were put into test at different times and therefore have various periods of exposure. Table 4 lists hours of exposure to the corrosive environment through April 1990. Many of the panels remained in test after this date. Final salt fog duration results will be included in the proceedings for Phase III of the program.

All of the panels processed with candidate protection systems applied over thin IVD aluminum (less than 0.0003 inch) exhibited outstanding corrosion resistance protection. Figures 18 and 19 are examples of protection systems applied over thin IVD aluminum that are still in test for 2500 hours beyond failure of the same protection system applied to bare (no IVD aluminum) panels. Whereas the supplemental protection system offers significant protection by itself on bare areas, the presence of some IVD aluminum coating which does occur on portions of the internal surface further enhances corrosion resistance.

e. Environmental Impact - The functional merits of IVD aluminum versus cadmium processing have been thoroughly discussed in the Phase I Data Base Handbook (Reference 1). However, the most important reason for replacing cadmium with IVD aluminum at the ALCs may be in how the two metals and their respective processing procedures impact the environment.

Aluminum is a non-toxic substance, and the IVD vacuum-coating process is a dry, environmentally clean process. Cadmium, on the other hand, is classified as toxic to humans; waste cadmium must be handled and disposed

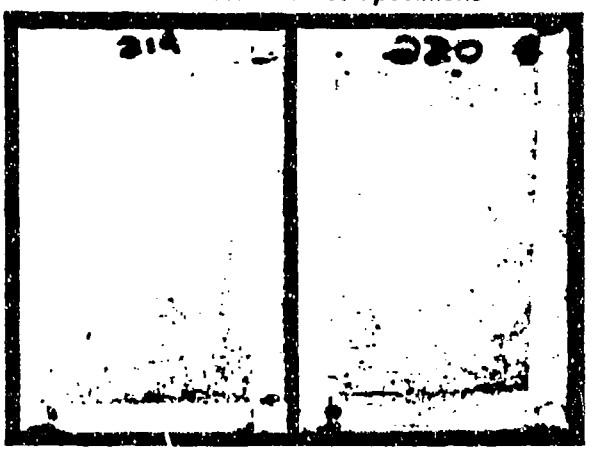
TABLE 4. CORROSION RESISTANCE OF CANDIDATE PROTECTION SYSTEMS IN A FIVE PERCENT NEUTRAL SALT FOG ENVIRONMENT.

	Alloy Steel Test Panels ASTM-B117 Salt Fog Resistance			
	Bare Steel		Thin IVD Al on Bare Steel	
Processor: Sacrificial Protection System	672 hr	Duration (hrs)	672 hr	Duration (hrs)
MCAIR: Alseal 518	Passed	6,048[b]	Passed	6,048[b]
MCAIR: Xylar I	Passed	6,024[b]	Passed	6,024[b]
Sermatech: Sermetel CR984-LT	Passed	1,704[b]	Not Tested	–
Processor: Barrier Protection System[a]				
MCAIR: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat	Passed	7,176[b]	Passed	7,176[b]
MCAIR: Epoxy Primer, Polysulfide Sealant "Fill and Drain"	Passed	7,152[b]	Passed	7,152[b]
MCAIR: P-92 Primer, Xylan 1014 Topcoat	Failed	–	Passed	6,192[b]
MCAIR: P-92 Primer, Xylan 1010 Topcoat	Failed	–	Passed	3,672
MCAIR: Waterborne Epoxy Primer, Polysulfide Sealant	Passed	1,980	Passed	6,024[b]
Embee Plating: Zinc Phosphate, Epoxy Primer, Polyurethane Topcoat	Passed	5,208[b]	Passed	5,208[b]
DeSoto: Epoxy Primer, Epoxy Powder Coating	Passed	2,448	Passed	4,632[b]
DeSoto: Waterborne Epoxy Primer, Epoxy Powder Coating	Passed	4,632[b]	Passed	4,632[b]
DeSoto: Navy Unicoat, Epoxy Powder Coating	Passed	2,760	Not Tested	–
DeSoto: Epoxy Powder Coating	Passed	4,536[b]	Passed	4,536[b]
Sunbelt Coating: Zinc Phosphate, P-92 Primer, Xylan 1014 Topcoat	Passed	692	Passed	4,488
Sunbelt Coating: Zinc Phosphate, Zylan 5611 Primer, Xylan 5251 Topcoat	Passed	1,368	Not Tested	–
MCAIR: Manganese Phosphate Waterborne Epoxy Primer, High-Solids Polyurethane Topcoat	Passed	1,536[b]	Not Tested	–

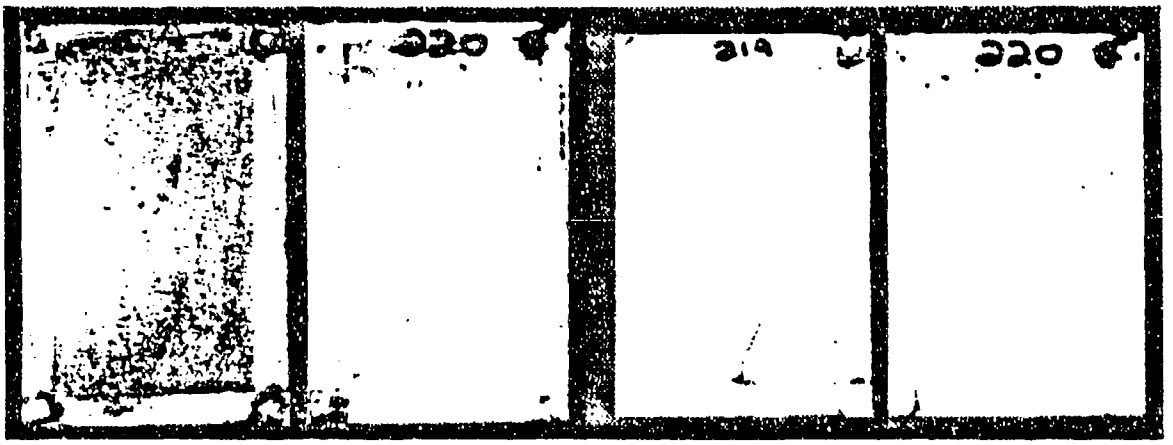
a Although these systems are designated barriers, some component materials contain leachable compounds which provide sacrificial protection – see Table 1.

b Panels are still in test.

Corrosion Resistance Specimens



Bare Steel
Overcoated With Alseal 518
672 Hours – 5% Neutral Salt Fog

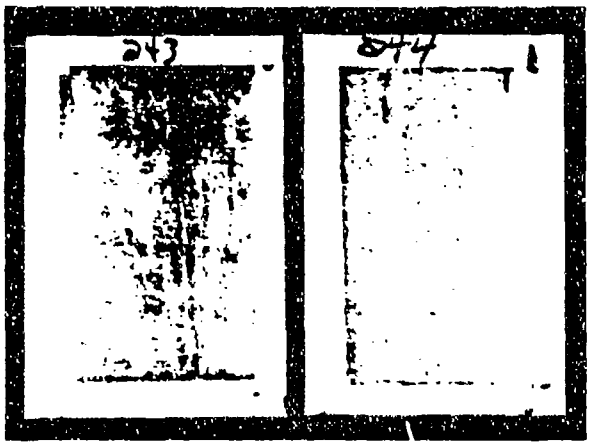


Bare Steel
Overcoated With Alseal 518
1,344 Hours – 5% Neutral Salt Fog

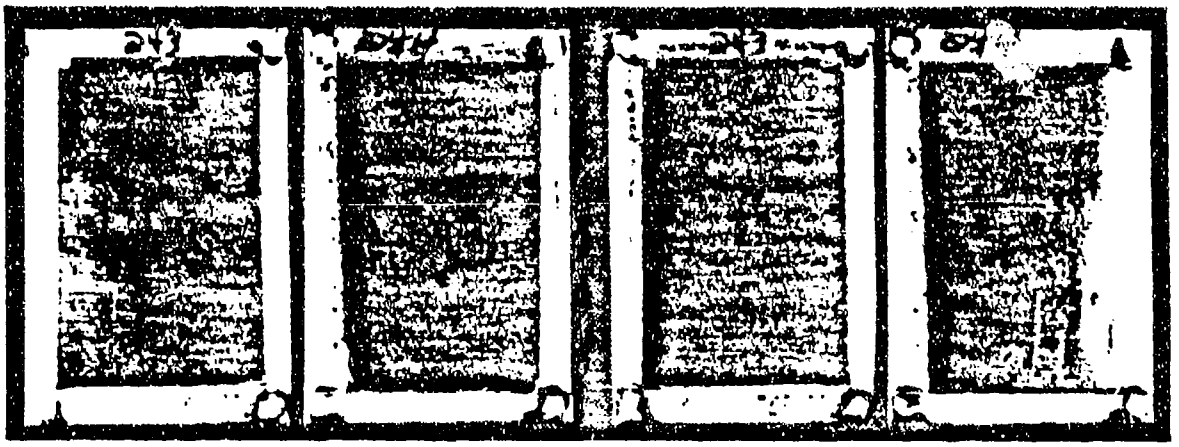
Bare Steel
Overcoated With Alseal 518
2,016 Hours – 5% Neutral Salt Fog

Figure 4. Corrosion Resistance: Alseal 518 Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



Bare Steel
Overcoated With Xylar 1
672 Hours – 5% Neutral Salt Fog

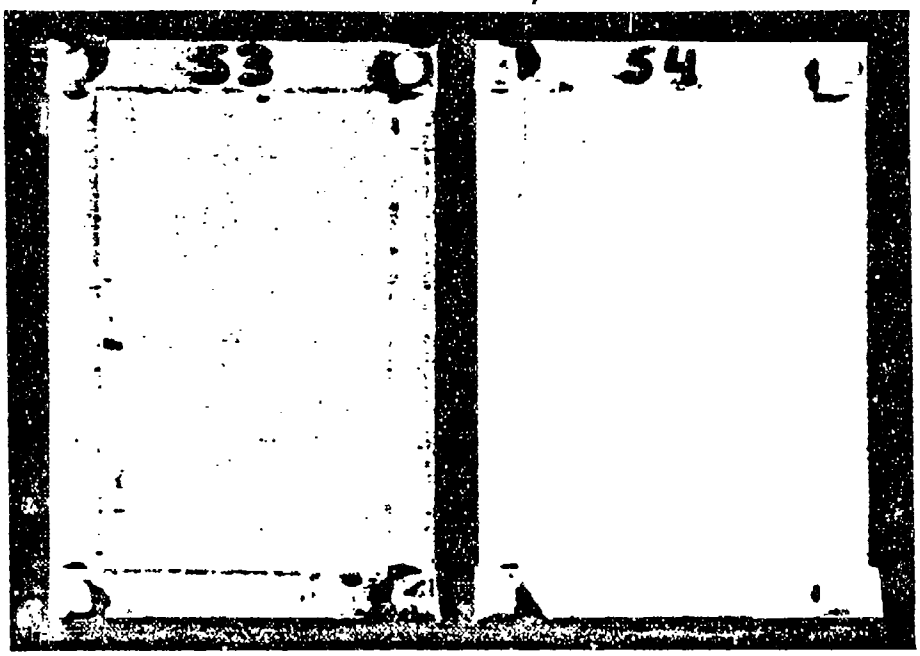


Bare Steel
Overcoated With Xylar 1
1,344 Hours – 5% Neutral Salt Fog

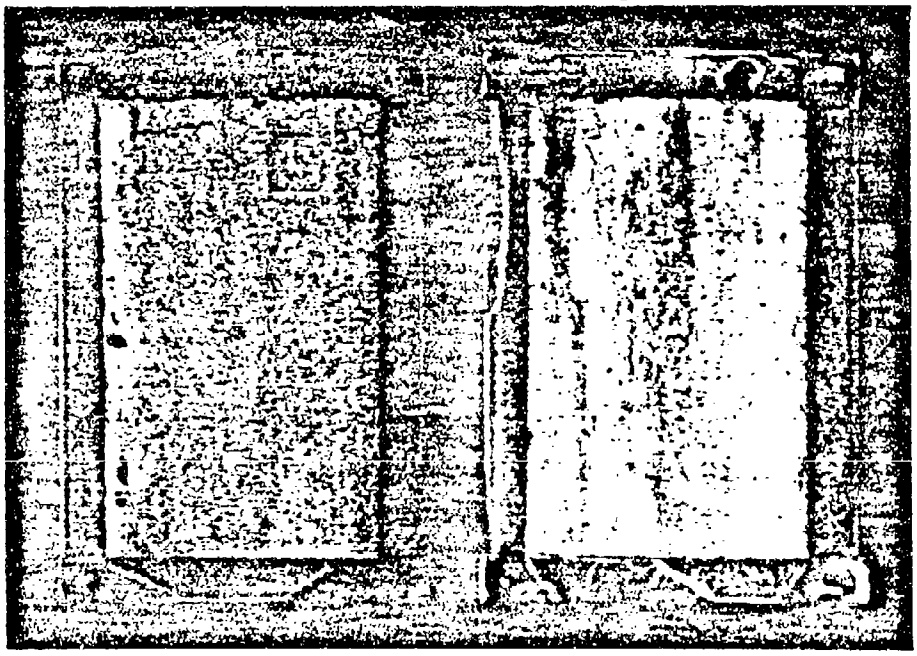
Bare Steel
Overcoated With Xylar 1
5,016 Hours – 5% Neutral Salt Fog

Figure 5. Corrosion Resistance: Xylar I Protection System Applied to Bare Alloy Steel Panels

Corrosion Resistance Specimens



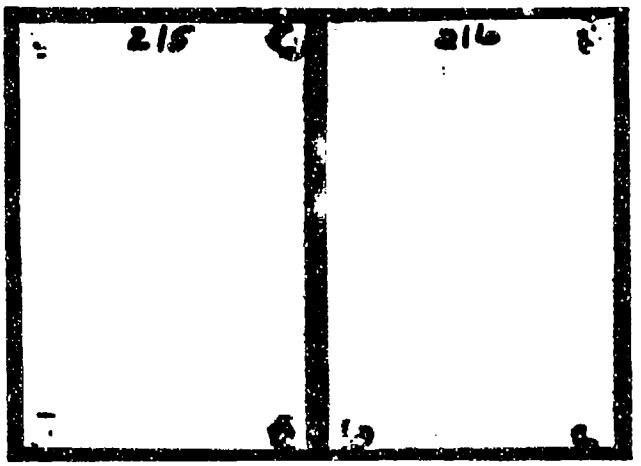
Bare Steel
Overcoated With Sermetel CR984-LT
672 Hours – 5% Neutral Salt Fog



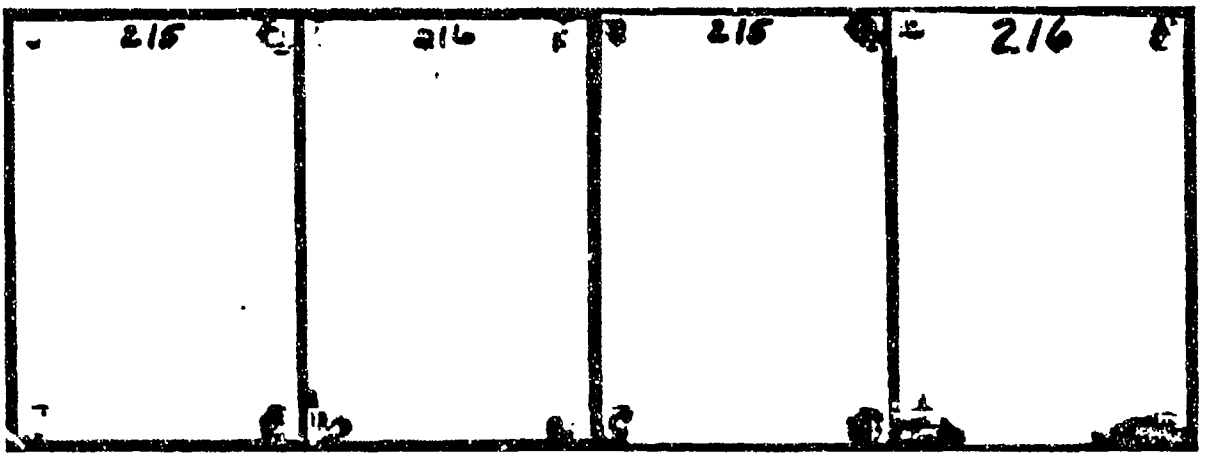
Bare Steel
Overcoated With Sermetel CR984-LT
1,344 Hours – 5% Neutral Salt Fog

Figure 6. Corrosion Resistance: Sermetel CR984-LT Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



Bare Steel
Primer, Sealant and Topcoat
672 Hours – 5% Neutral Salt Fog

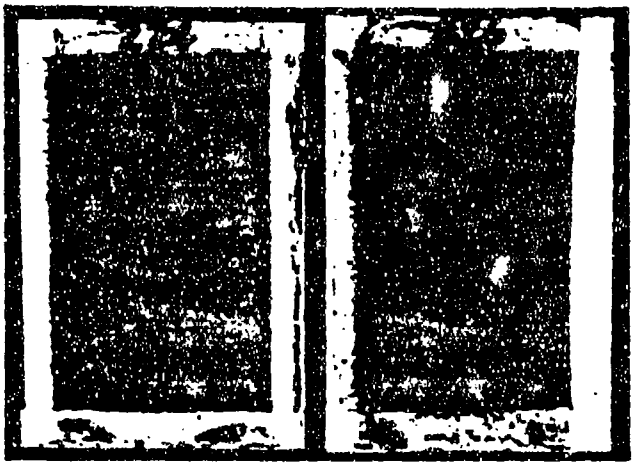


Bare Steel
Primer, Sealant and Topcoat
1,344 Hours – 5% Neutral Salt Fog

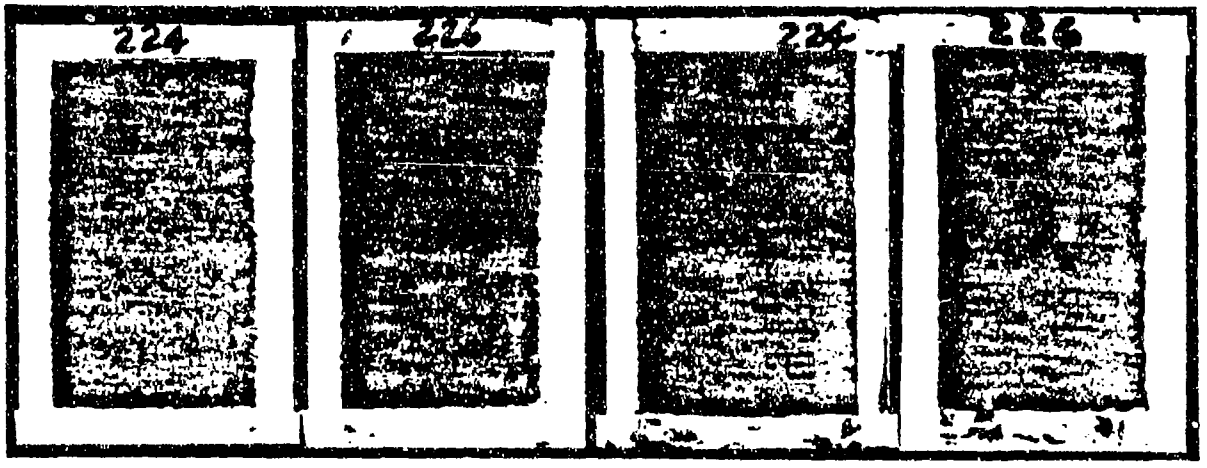
Bare Steel
Primer, Sealant and Topcoat
4,032 Hours – 5% Neutral Salt Fog

Figure 7. Corrosion Resistance: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



Bare Steel
Overcoated With MCAIR Fill and Drain
672 Hours – 5% Neutral Salt Fog

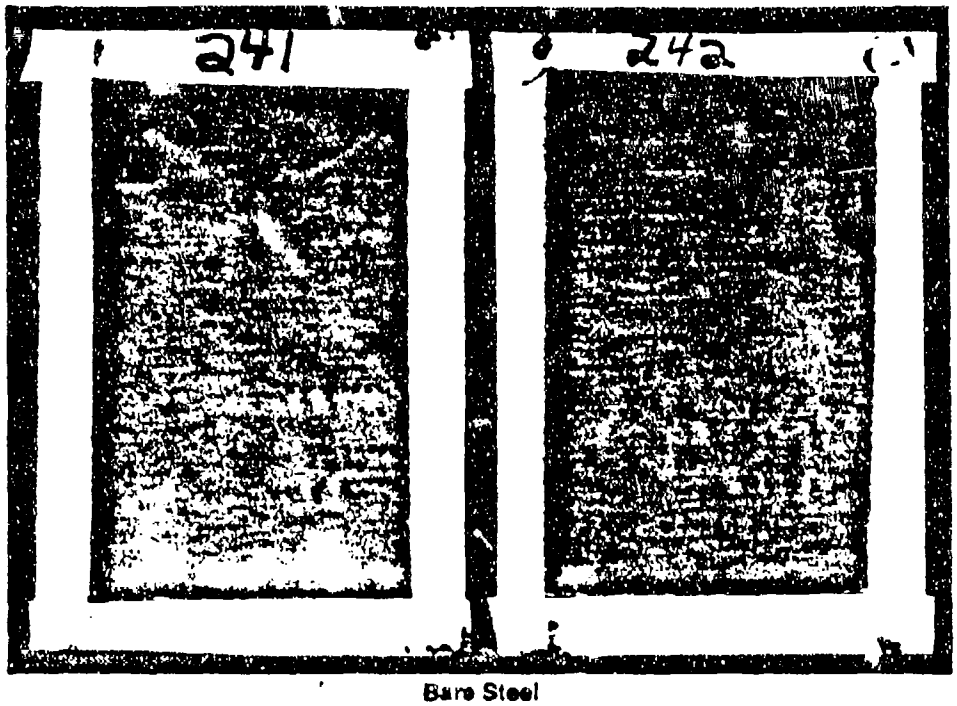


Bare Steel
Overcoated With MCAIR Fill and Drain
1,344 Hours – 5% Neutral Salt Fog

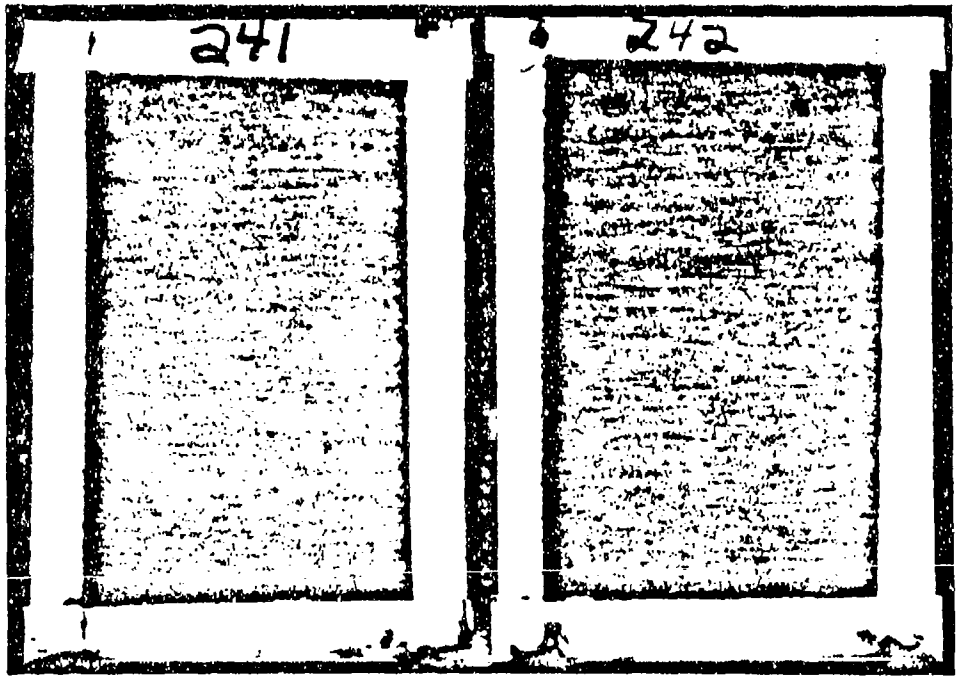
Bare Steel
MCAIR Fill and Drain
4,032 Hours – 5% Neutral Salt Fog

Figure 8. Corrosion Resistance: Epoxy Primer, Polysulfide Sealant "Fill and Drain" Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



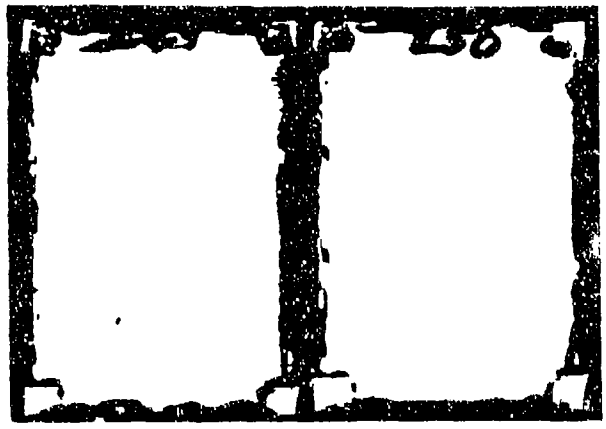
Bare Steel
Overcoated With Waterborne Primer and Sealant
672 Hours – 5% Neutral Salt Fog



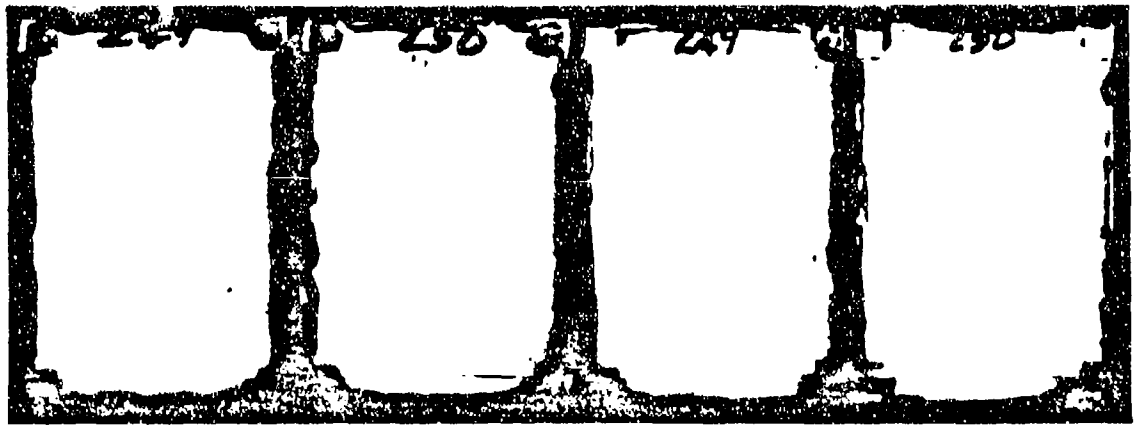
Bare Steel
Waterborne Primer and Sealant
1,344 Hours – 5% Neutral Salt Fog

Figure 9. Corrosion Resistance: Waterborne Epoxy Primer and Polysulfide Sealant Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



Bare Steel
Phosphate Coating, Primer and Paint
672 Hours – 5% Neutral Salt Fog

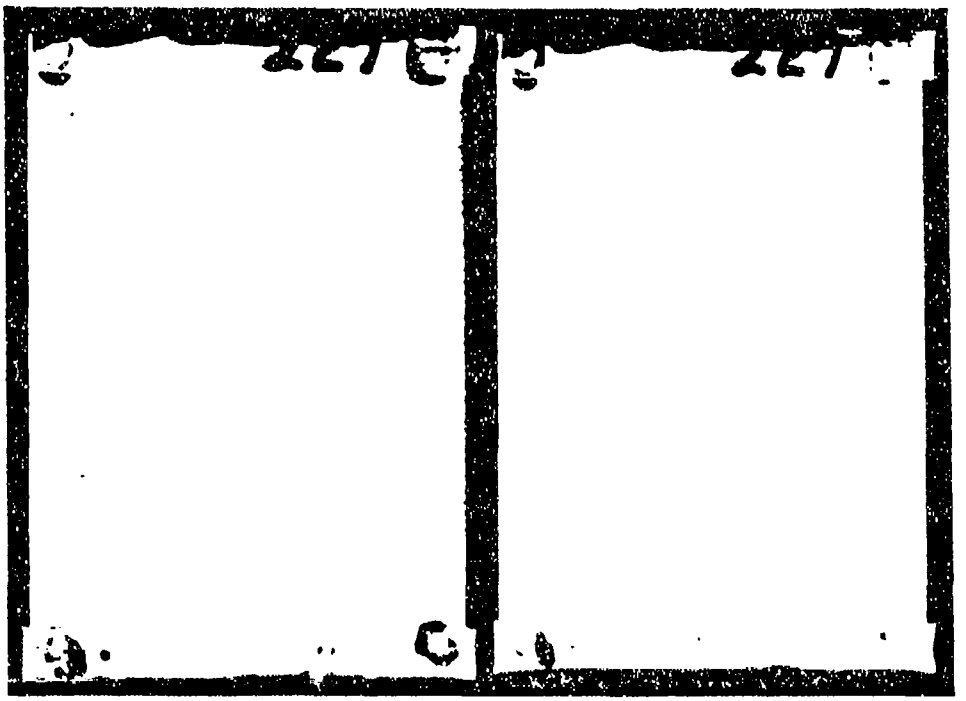


Bare Steel
Phosphate Coating, Primer and Paint
2,016 Hours – 5% Neutral Salt Fog

Bare Steel
Phosphate Coating, Primer and Paint
4,200 Hours – 5% Neutral Salt Fog

Figure 10. Corrosion Resistance: Zinc Phosphate, Epoxy Primer, Polyurethane Topcoat Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimen

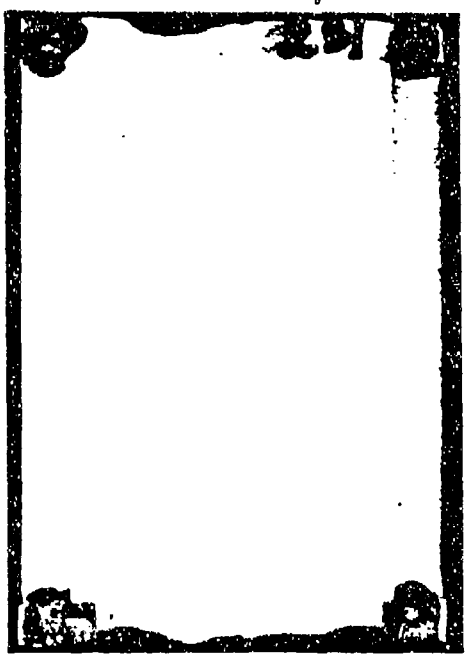


Bare Steel
Primer and Powder Coating
672 Hours – 5% Neutral Salt Fog

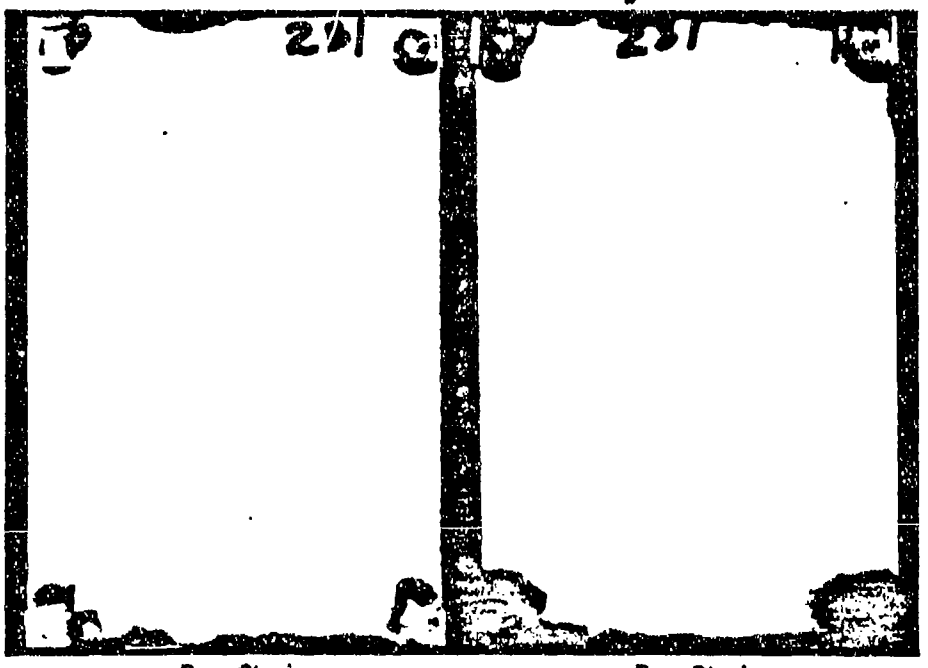
Bare Steel
Primer and Powder Coating
1,344 Hours – 5% Neutral Salt Fog

Figure 11. Corrosion Resistance: Epoxy Primer, Epoxy Powder Coating Protection System Applied to a Bare Alloy Steel Panel.

Corrosion Resistance Specimen



Bare Steel
Waterborne Primer and Powder Coating
672 Hours – 5% Neutral Salt Fog

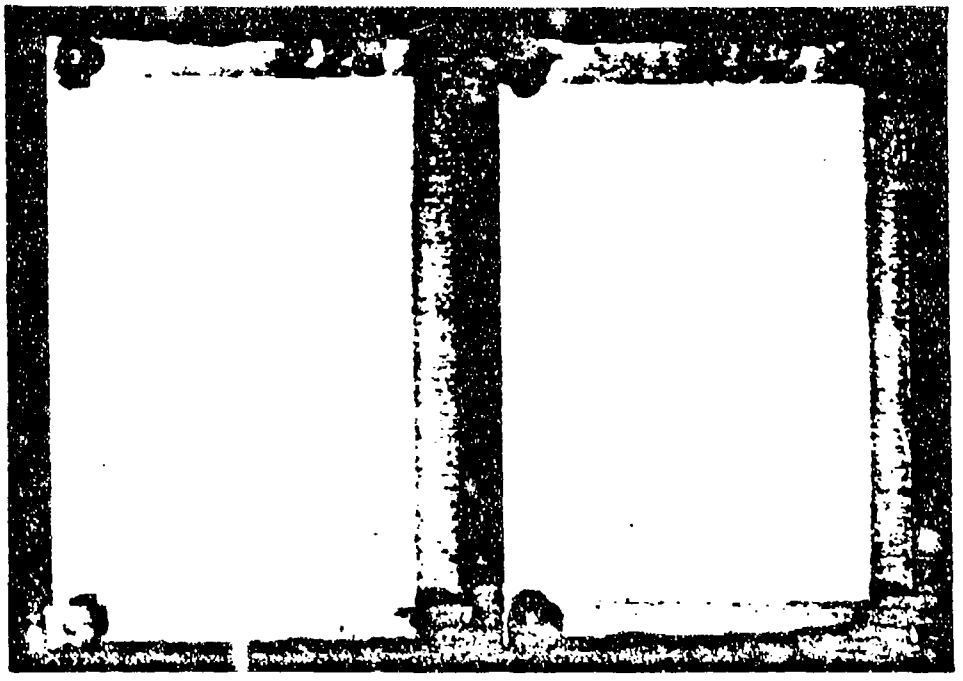


Bare Steel
Waterborne Primer and Powder Coating
1,344 Hours – 5% Neutral Salt Fog

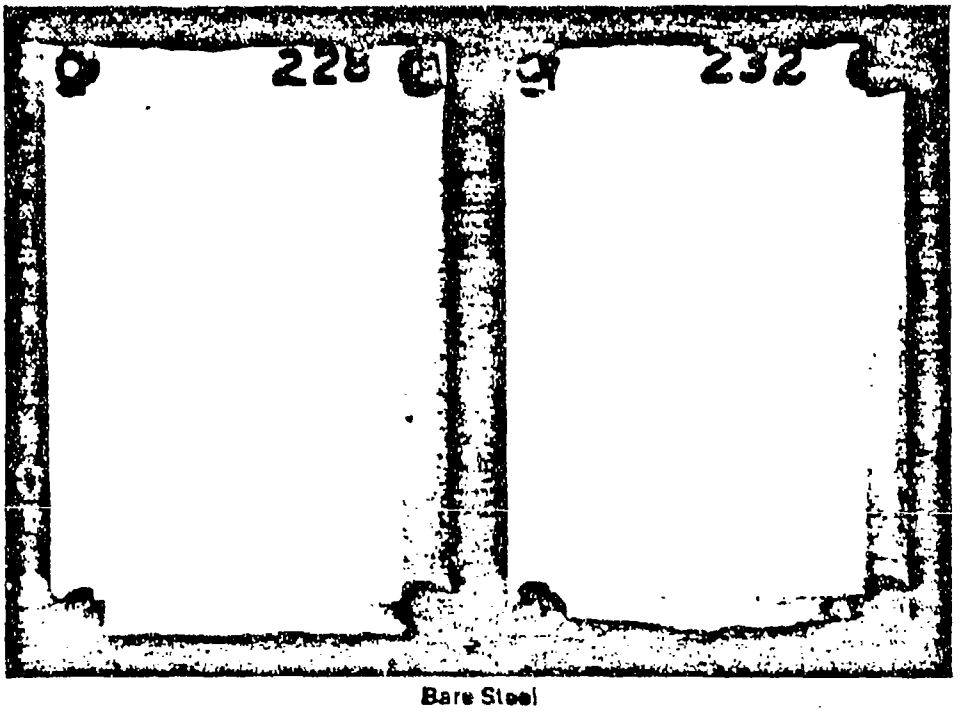
Bare Steel
Waterborne Primer and Powder Coating
3,624 Hours – 5% Neutral Salt Fog

Figure 12. Corrosion Resistance: Waterborne Epoxy Primer and Epoxy Powder Coating Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



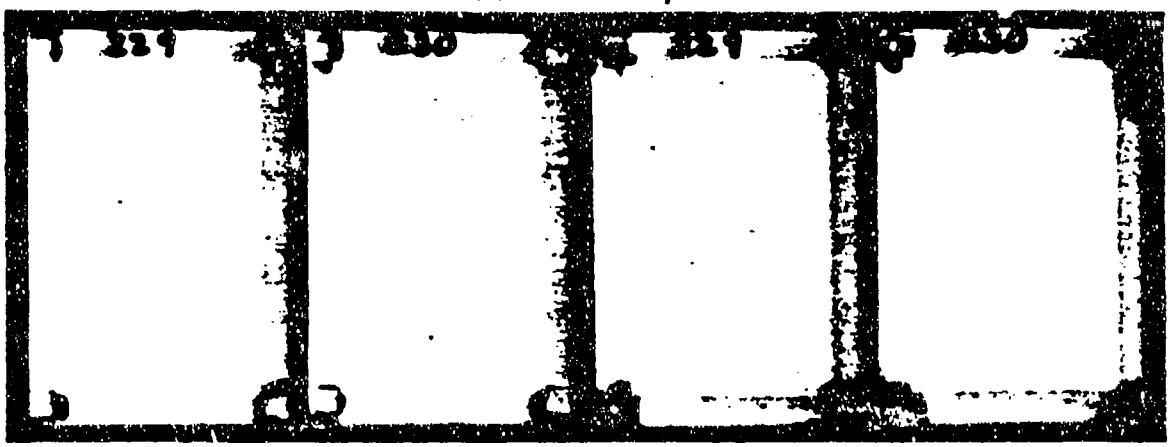
Bare Steel
Navy Unicoat and Powder Coating
672 Hours – 5% Neutral Salt Fog



Bare Steel
Navy Unicoat and Powder Coating
1,344 Hours – 5% Neutral Salt Fog

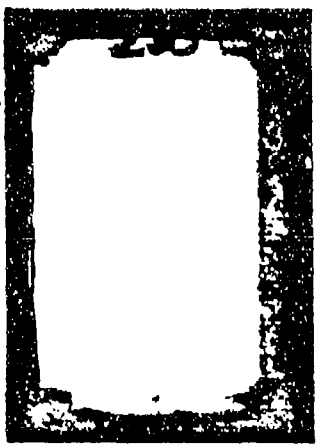
Figure 13. Corrosion Resistance: Navy Unicoat and Epoxy Powder Coating Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistance Specimens



Bare Steel
Powder Coating
672 Hours – 5% Neutral Salt Fog

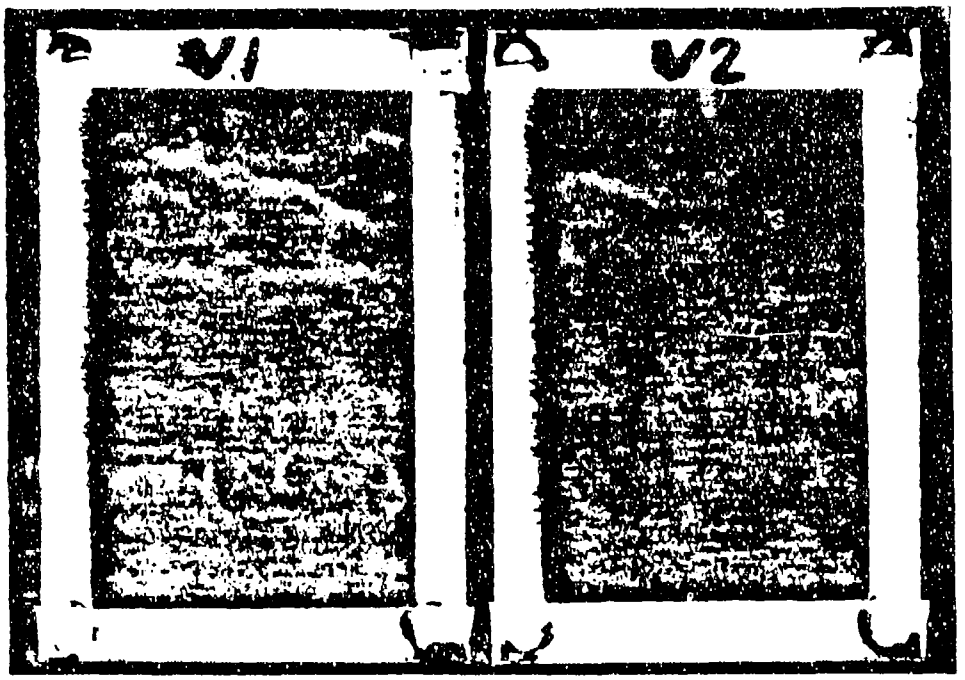
Bare Steel
Powder Coating
1,344 Hours – 5% Neutral Salt Fog



Bare Steel
Powder Coating
3,528 Hours – 5% Neutral Salt Fog

Figure 14. Corrosion Resistance: Epoxy Powder Coating Protection System Applied to Bare Alloy Steel Panels.

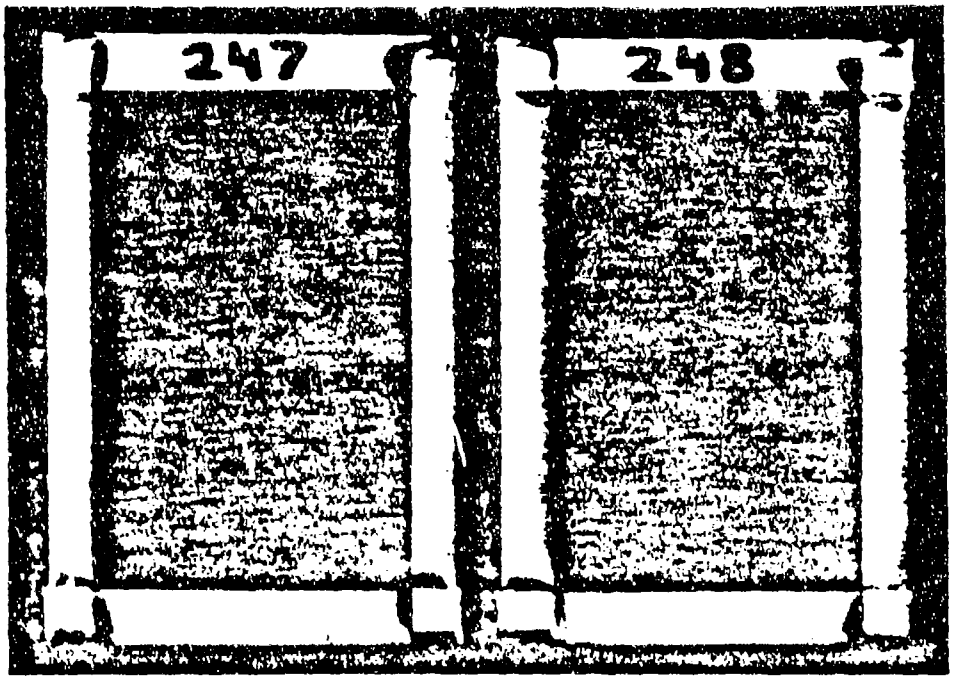
Corrosion Resistance Specimens



Bare Steel
Zinc Phosphate, Zinc-Rich Primer and One Coat of Xylan 5000 Series Coating
1,008 Hours – 5% Neutral Salt Fog

Figure 15. Corrosion Resistance: Zinc Phosphate, Zinc-Rich Primer, Xylan 5000 Series Topcoat Protection System Applied to Bare Alloy Steel Panels.

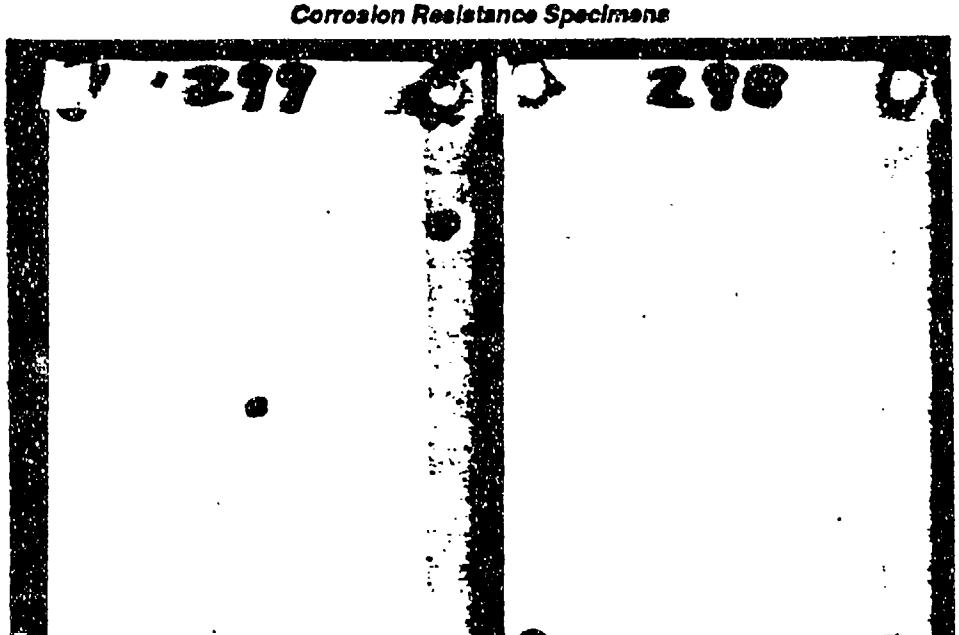
Corrosion Resistance Specimens



Bare Steel
Phosphate Coating, Prime and Xylan 1014
672 Hours – 5% Neutral Salt Fog

Figure 16. Corrosion Resistance: Zinc Phosphate, P-92 Primer, Xylan 1014 Topcoat Protection System Applied to Bare Alloy Steel Panels.

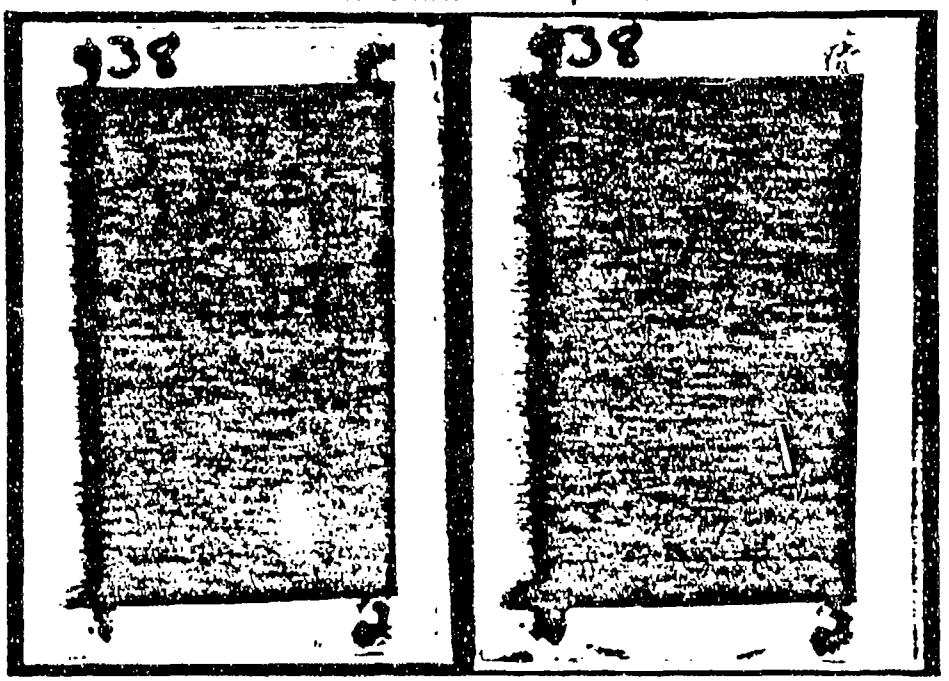
Corrosion Resistance Specimens



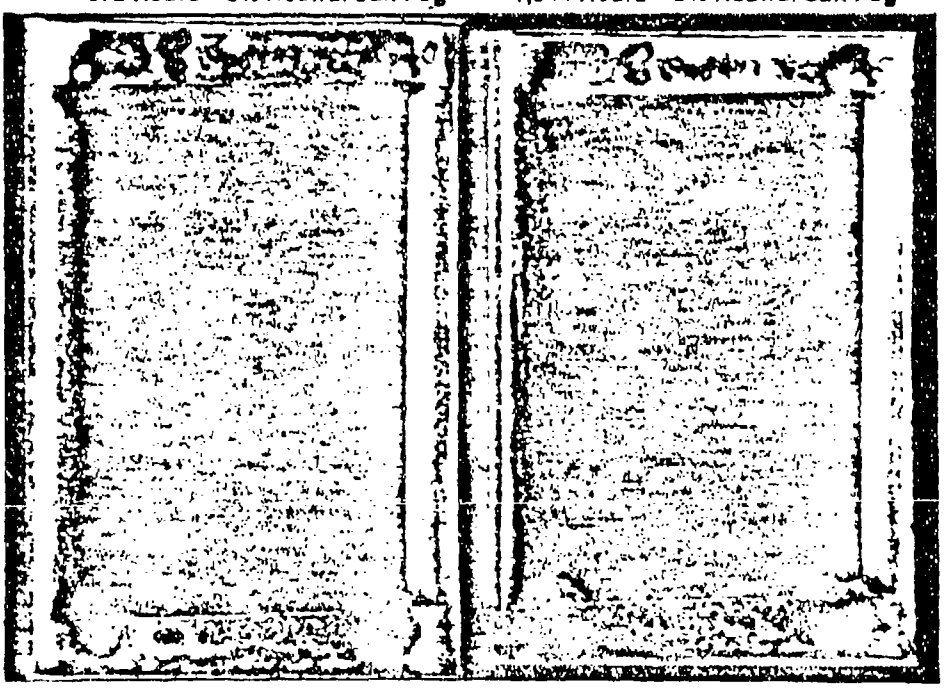
Bare Steel
Phosphate, Waterborne Primer, High-Solids Topcoat
672 Hours – 5% Neutral Salt Fog

Figure 17. Corrosion Resistance: Manganese Phosphate, Waterborne Epoxy Primer, High-Solids Polyurethane Protection System Applied to Bare Alloy Steel Panels.

Corrosion Resistant Specimen



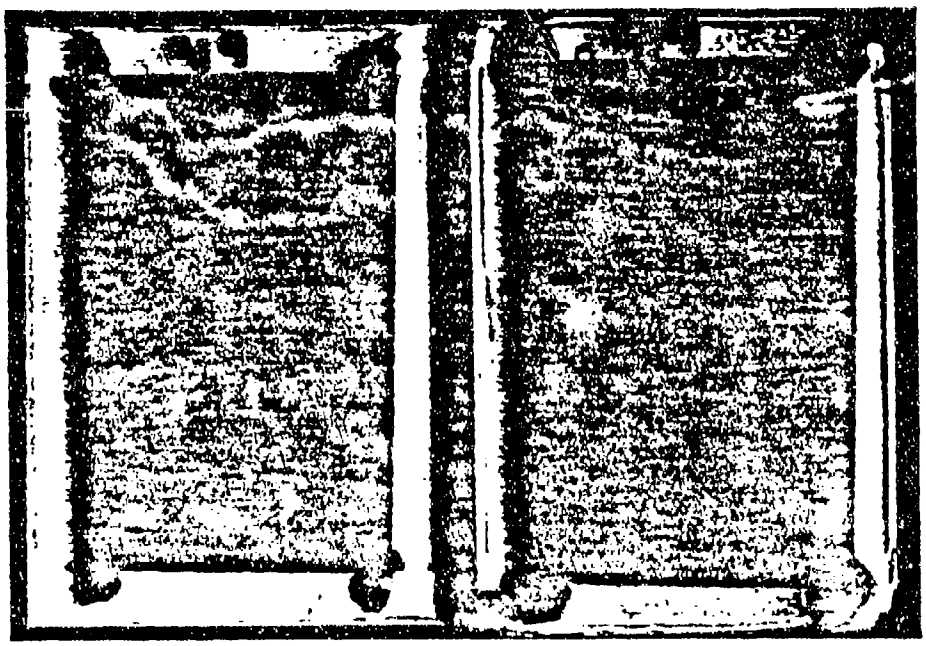
IVD Aluminum Coated Steel Panel – Peened, Type II
Overcoated With Waterborne Primer and Sealant
672 Hours – 5% Neutral Salt Fog 1,344 Hours – 5% Neutral Salt Fog



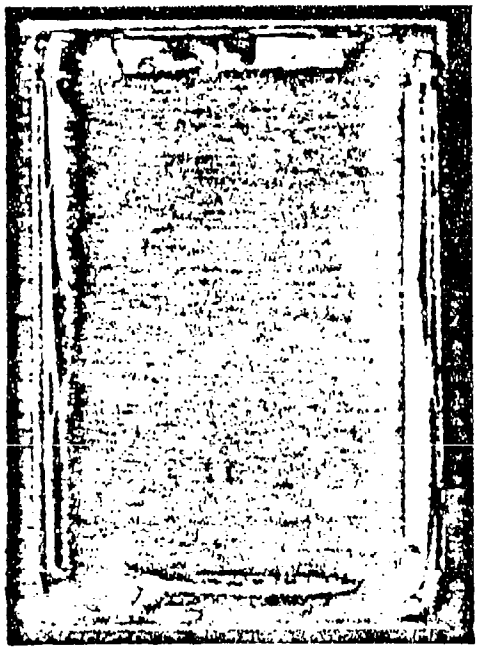
IVD Aluminum Coated Steel Panel – Peened, Type II
Overcoated With Waterborne Primer and Sealant
2,688 Hours – 5% Neutral Salt Fog 5,424 Hours – 5% Neutral Salt Fog

Figure 18. Corrosion Resistance: Waterborne Epoxy Primer and Polysulfide Sealant Protection System Applied to Alloy Steel Panel Coated With Thin IVD Aluminum.

Corrosion Resistant Specimen



IVD Aluminum Coated Steel Panel – Peened, Type II
Overcoated With Phosphate, Primer and Xylan 1014
672 Hours – 5% Neutral Salt Fog 1,344 Hours – 5% Neutral Salt Fog



IVD Aluminum Coated Steel Panel – Peened, Type II
Overcoated With Phosphate, Primer and Xylan 1014
3,888 Hours – 5% Neutral Salt Fog

Figure 19. Corrosion Resistance: Zinc Phosphate, P-92 Primer, Xylan 1014 Topcoat Protection System Applied to Alloy Steel Panel Coated With Thin IVD Aluminum.

of as a hazardous waste by approved Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) procedures. In addition, electroplated cadmium processing introduces additional hazardous materials, such as cyanide in the plating bath, which must be controlled. The thrust to eliminate cadmium processing at the ALCs will reduce hazardous waste production and improve environmental compliance in general.

It is important therefore for supplemental processing that is performed in conjunction with normal IVD aluminum processing be environmentally compliant. Table 8 addresses the environmental compliance of the candidate protection systems. MCAIR included barrier-type coatings in the evaluation that currently meet the most stringent aerospace volatile organic compound (VOC) regulations. Current aircraft paint primers contain chromium corrosion inhibitors which will be controlled by air-toxic regulations that are currently being enacted. The aerospace industry is currently evaluating alternate corrosion inhibitors.

2. Simulated Production Details

Four-inch diameter by 18-inch long 4130 alloy steel cylinders were selected to simulate production details such as landing gear details. After being processed with IVD aluminum, these detail parts were adequately coated on external surfaces and on internal surfaces for a distance of about four inches from each end. The remaining ten inches of internal surface in the middle of the cylinder received a very thin (less than 0.0002 inch) coating which transitioned to no coating at all (see Figure 2). Ten IVD aluminum-coated cylinders were further processed with the supplemental internal surface protection systems listed in Table 8. The cylinders were then sectioned lengthwise (Figure 20). After thickness and uniformity were measured, the supplemental protection systems were tested for adhesion and corrosion resistance.

TABLE 5. HEALTH AND ENVIRONMENTAL IMPACT OF CANDIDATE PROTECTION SYSTEMS

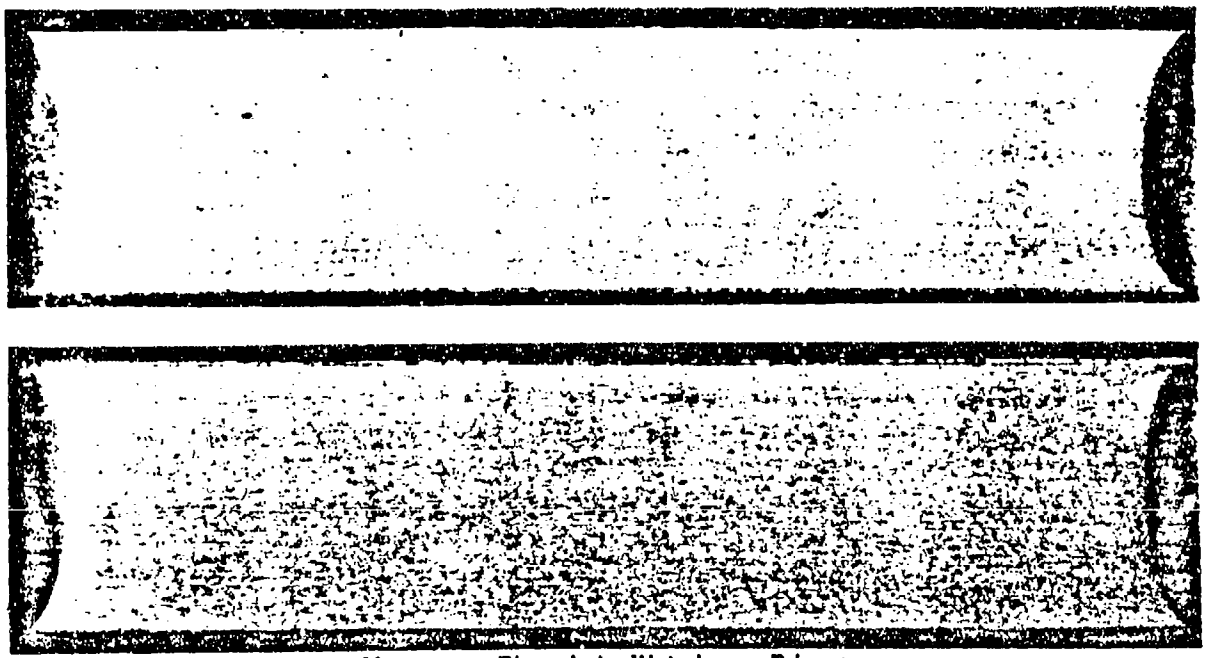
Candidate Protection System	Volatile Organic Compound (VOC)		Known/Suspected Carcinogen [b]	Personal Exposure Limit (PEL) of Solvent [c]
	Actual (grams/liter)	South California Limit (grams/liter) [a]		
Alseal 518	0	420	Yes	–
Xylar I	0	420	Yes	–
Sermatel CR984-LT	0	420	Yes	–
Epoxy Primer	578	350	Yes	50
Polysulfide Sealant (Brush)	271	600	No	100
Polyurethane Topcoat	590	420	No	25
Epoxy Primer	675	350	Yes	100
Polysulfide Sealant (Fill and Drain)	403	600	No	100
P-92 Primer	818	350	No	10
Xylan 1014 Topcoat	769	420	No	10
P-92 Primer	818	350	No	10
Xylan 1010 Topcoat	767	420	No	10
Waterborne Epoxy Primer	345	350	Yes	25
Polysulfide Sealant (Spray)	403	600	No	100
Zinc Phosphate	0		Yes	–
Epoxy Primer	575	350	Yes	100
Polyurethane Topcoat	590	420	No	25
Epoxy Primer	675	350	Yes	100
Epoxy Powder Coating	0	420	No	–
Waterborne Epoxy Primer	345	350	Yes	25
Epoxy Powder Coating	0	420	No	–
NADC Unicoat	420	600	No	50
Epoxy Powder Coating	0	420	No	–
Epoxy Powder Coating	0	420	No	–
Zinc Phosphate	0		Yes	–
P-92 Primer	818	350	No	10
Xylan 1014	769	420	No	10
Zinc Phosphate	0		Yes	–
Xylan 5611 Primer	589	350	Yes	100
Xylan 5251	583	420	Yes	1
Manganese Phosphate	0		Yes	–
Waterborne Epoxy Primer	345	350	Yes	25
High-Solids Polyurethane Topcoat	415	420	No	50

a South Coast Air Quality Management Rule 1124 -- current or scheduled regulation.
b "Yes" materials contain chromium corrosion inhibitors.
c Lowest PEL if more than one solvent.

TABLE 6. SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO THE INTERNAL SURFACES OF THE 4-INCH DIAMETER BY 18-INCH LONG CYLINDERS.

Processor: Protection System	
MCAIR	• Alseal 518 • Alseal 518, Waterborne Primer, Polyurethane Topcoat • Waterborne Primer, Polysulfide Sealant (Sprayed) • Waterborne Primer, Polysulfide Sealant (Brushed) • Waterborne Primer, Polysulfide Sealant (Fill and Drain) • Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat
Embee Plating	• Manganese Phosphate, Epoxy Primer, Polyurethane Topcoat
Embee/MCAIR	• Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Topcoat
DeSoto	• Epoxy Primer, Epoxy Powder Coating • Waterborne Primer, Epoxy Powder Coating

Cylinder Corrosion Test Specimens



Manganese Phosphate, Waterborne Primer,
High-Solids Polyurethane Enamel Topcoat

GP03-0180-25

Figure 20. 4-Inch Diameter by 18-Inch Long Cylinder Sectioned After Processing For Testing.

a. Processing Parameters - The bare steel cylinders were processed in the following sequence:

(1) IVD aluminum preclean - Standard precleaning was used which consists of:

o Solvent vapor degreasing to remove organic contaminants from the part surface such as grease and oil films, cutting fluids, and corrosion prevention compounds.

o Grit blasting at 60-70 psi with aluminum oxide to abrasively remove surface oxides. Note: Clean, dry air is required.

(2) IVD Aluminum Application - The cylinders were coated with IVD aluminum per MIL-C-83488, Class 1, Type II. Class 1 requires a minimum of 0.001 inch of coating on the external surfaces of the cylinders. Type II requires that the aluminum coating be treated with chromate conversation coating per MIL-C-5541.

(3) IVD aluminum post-coat procedures - The following procedures were performed on all of the cylinders except for the one that was further processed with Alseal 518:

o The IVD aluminum coating was burnished (peened) with glass beads at 40 psi prior to chromate conversation coating. Burnishing not only improves corrosion resistance by densifying the coating but also serves as a simple, supplemental adhesion check of the coating.

o All of the cylinders were chromated within 24 hours of peening per the following procedure:

Immerse cylinders in Alodine 1200 solution for 30 seconds.

- Rinse cylinders thoroughly with ambient temperature tap water to remove all excess Alodine 1200 solution.

- Blow the cylinders dry immediately with clean, dry compressed air.

- Protect the chromated cylinders from contamination and moisture.

Note: Peening deoxidizes the IVD aluminum coating and enables a complete chemical reaction between the IVD aluminum coating and chromate conversion solution. Repeen the IVD aluminum coating if chromating does not occur within 24 hours.

Exception: The cylinder processed with Alseal 518 was peened and chromated after the Alseal 518 was applied.

(4) Supplemental Protection System Application - The cylinders were then further processed with the various Table 6 protection systems per the applicable Table 7 procedure.

b. Thickness/Uniformity - The total coating system thickness and uniformity as measured with a Dualscope is shown in Table 8.

c. Coating System Adhesion - The mil-specs controlling the components of the various barrier-type protection systems all impose stringent coating adhesion testing for material qualification. All barrier-type coatings that were applied to cylinder internal surfaces were qualified mil-spec materials other than powder coating. The basic requirements for materials with proven good adhesion characteristics is proper substrate cleaning and application of the material. The internal surfaces were already basically clean from IVD aluminum processing but were grit-blasted again just prior to application of the protection system components per Table 7. The inherent adhesion of Alseal 518 sacrificial-type coatings is not as good as

TABLE 7. PROCESSING PROCEDURES FOR SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO INTERNAL SURFACES.

Processor: Protection System[a]	Processing Procedure
MCAIR: Aseal 518	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. One Coat of Aseal 518 Was Spray Applied Using Conventional Air Spray Equipment With a 90° Spray Extension. The First Coat Was Cured at Room Temperature for 15 Minutes, Then Baked At 175°F for 45 Minutes. A Second Coat Was Applied and Baked at 175°F. The Completed Coating Was Then Cured at 500°F for 60 Minutes. The Cylinder Was Cut In Two Sections. The Aseal 518 Coating Was Glass Bead Peened at 25 psi to Burnish the Coating for Electrical Conductivity Recommended Production Procedure – In Production, a 360° Spray Extension Should Be Used for All Internal Diameter Spray Applications. The Glass Bead Peening Would Be Performed Using a 90° Nozzle. The Aseal 518 Would Be Overcoated With One Coat of Primer and Two Coats of Polyurethane Topcoat
MCAIR: Aseal 518, Waterborne Primer, Polyurethane Topcoat	Cylinder Procedure – A Cylinder Processed With Aseal 518 Was Then Coated With One Coat of MIL-P-85582 Waterborne Primer and Two Coats of MIL-C-83286 Gloss White Polyurethane Enamel. All of the Coatings Were Spray Applied Using Conventional Air Spray Equipment With a 90° Spray Extension. Each Coat Was Baked for 30 Minutes at 150°F Recommended Production Procedure – A 360° Spray Extension Should Be Used for All Internal Diameter Spray Applications.
MCAIR: Waterborne Primer, Polysulfide Sealant (Sprayed)	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. One Coat of MIL-P-85582 Waterborne Primer Was Spray Applied Using Conventional Air Spray Equipment With a 90° Spray Extension. The Primer Was Cured for 30 Minutes at 160°F. One Coat of MIL-S-83430 Polysulfide Sealant Was Spray Applied and Allowed to Cure for 24 Hours at Room Temperature. Class A-4 Sealant Was Thinned 30 Percent by Volume With Toluene. A Second Coat of Sealant Was Spray Applied. The Coating System Was Cured for 7 Days at Room Temperature Recommended Production Procedure – A 360° Spray Extension Should Be Used for All Internal Diameter Spray Applications.
MCAIR: Waterborne Primer, Polysulfide Sealant (Brushed)	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. One Coat of MIL-P-85582 Waterborne Primer Was Brush Applied and Baked for 30 Minutes at 160°F. One Coat of MIL-S-83430 Polysulfied Sealant Was Brush Applied and Allowed to Cure for 24 Hours at Room Temperature. Class A-1/2 Sealant Was Thinned 10 Percent by Volume With Toluene. A Second Coat of Sealant Was Brush Applied. The Coating System Was Cured for 7 Days at Room Temperature Recommended Production Procedure – Same as Cylinder Procedure

a See Table 1 for supplier, processor and Mil-spec information.

TABLE 7. PROCESSING PROCEDURES FOR SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO INTERNAL SURFACES (CONTINUED).

Processor: Protection System[a]	Processing Procedure
MCAIR: Waterborne Primer, Polysulfide Sealant (Fill and Drain)	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. The Cylinder Was Fill and Drain Coated With One Coat of MIL-P-85582 Waterborne Primer and Baked for 30 Minutes at 160°F. The Cylinder Was Fill and Drain Coated With MIL-S-83430 Polysulfide Sealant and Allowed to Cure for 24 Hours at Room Temperature. Class A-1/2 Sealant Was Thinned 30 Percent by Volume With Tolune. A Second Coat of Sealant Was and Drain Applied. The Coating System Was Cured for 7 Days at Room Temperature. Recommended Production Procedure – Same as Cylinder Procedure.
MCAIR: Epoxy Primer Polysulfide Sealant, Polyurethane Topcoat	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. Two Coats of MIL-P-23377 Primer Were Brushed Applied With a 30 Minute Bake at 160°F After Each Coat. One Coat of MIL-S-83430 Polysulfide Was Brush Applied and Allowed to Cure for 24 Hours at Room Temperature. Class A-1/2 Sealant Was Thinned 10 Percent by Volume With Tolune. Two Coats of MIL-C-83286 Gloss White Polyurethane Enamel Were Brushed Applied. The Coating System Was Cured for 7 Days at Room Temperature. Recommended Production Procedure -- Same as Cylinder Procedure.
Embee Plating: Manganese Phosphate, Epoxy Primer, Polyurethane Topcoat	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi and Manganese Phosphate Coated Per MIL-P-16232. One Coat of MIL-P-23377 Primer and Two Coats of MIL-C-83286 Gloss White Polyurethane Enamel Were Spray Applied Using Conventional Air Spray Equipment With a 360° Spray Extension. Each Coat Was Cured at Room Temperature. Recommended Production Procedure – Same as Cylinder Procedures.
Embee/MCAIR: Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Topcoat	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi and Manganese Phosphate Coated Per MIL-P-16232. One Coat of MIL-P-85582 Waterborne Primer Was Spray Applied Using Conventional Air Spray Equipment With a 360° Spray Extension. The Primer Was Cured at Room Temperature. Two Coats of MIL-P-85285 Gloss White High Solids Polyurethane Topcoat Were Spray Applied Using Conventional Air Spray Equipment With a 90° Spray Extension. Each Coat of Topcoat Was Baked at 160°F for 30 Minutes. Recommended Production Procedures – A 360° Spray Extension Should Be Used for All Internal Diameter Spray Applications.

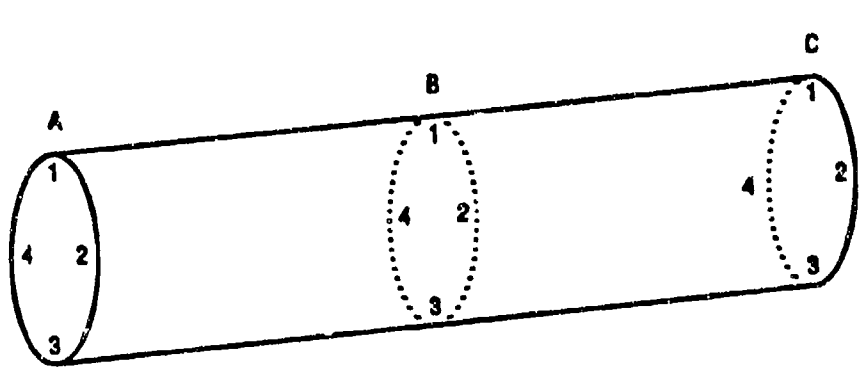
a See Table 1 for supplier, processor and Mil-spec information.

TABLE 7. PROCESSING PROCEDURES FOR SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO INTERNAL SURFACES (CONCLUDED).

Processor: Protection System[a]	Processing Procedure
DeSoto: Epoxy Primer, Epoxy Powder Coating	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. The Cylinder Was Fill and Drain Coated With One Coat of MIL-P-23377 Primer. The Primer Was Cured at Room Temperature. DeSoto Epoxy Powder Coating Was Applied Using a Fluidized Bed. The Powder Coating Was Cured at 250°F for 15 Minutes. Recommended Production Procedure – Same as Cylinder Procedure.
DeSoto: Waterborne Primer, Epoxy Powder Coating	Cylinder Procedure – Surface Was Grit Blasted With Aluminum Oxide Grit at 60 psi. The Cylinder Was Fill and Drain Coated With One Coat of MIL-P-85582 Waterborne Primer. The Primer Was Cured at Room Temperature. DeSoto Epoxy Powder Coating Was Applied Using a Fluidized Bed. The Powder Coating Was Cured at 250°F for 15 Minutes. Recommended Production Procedure – Same as Cylinder Procedure.

a See Table 1 for supplier, processor and Mil-spec information.

TABLE 8. UNIFORMITY AND AVERAGE THICKNESS OF SUPPLEMENTAL PROTECTION SYSTEMS (CYLINDER INTERNAL SURFACE).



Processor: Protection System	Protection Thickness (mils)												Average Thickness (mils)
	A				B				C				
	1	2	3	4	1	2	3	4	1	2	3	4	
MCAIR: Alseal 518	2.5	2.8	3.0	2.5	1.3	1.9	2.2	1.3	2.3	3.0	3.6	2.1	2.4
MCAIR: Alseal 518, Waterborne Primer, Polyurethane Topcoat	5.0	3.8	4.9	3.6	5.0	3.9	2.6	3.3	3.7	3.3	3.1	3.9	3.9
MCAIR: Waterborne Primer, Polysulfide Sealant (Sprayed)	4.2	6.8	6.8	9.5	6.5	6.1	5.5	8.2	7.3	4.1	5.7	8.1	6.6
MCAIR: Waterborne Primer, Polysulfide Sealant (Brushed)	4.1	4.3	4.4	5.3	4.5	2.8	3.5	3.5	3.0	3.3	2.8	2.6	3.7
MCAIR: Waterborne Primer, Polysulfide Sealant (Fill and Drain)	9.5	8.5	9.1	6.2	10.4	9.3	9.7	10.2	10.5	10.1	8.0	10.1	9.3
MCAIR: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat	5.2	5.8	4.3	4.4	4.3	5.5	5.0	4.0	4.9	5.6	4.8	4.3	4.8
Embee Plating: Manganese Phosphate, Epoxy Primer, Polyurethane Topcoat	3.2	3.6	3.8	3.3	3.0	3.2	3.0	3.0	3.2	3.8	3.5	3.0	3.3
Embee/MCAIR: Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Topcoat	3.7	3.5	3.3	3.4	4.0	3.7	3.3	3.7	3.7	4.0	3.6	4.1	3.7
DeSoto: Epoxy Primer, Epoxy Powder Coating	2.5	2.5	2.9	3.2	4.0	4.2	4.1	4.3	4.1	3.0	2.8	3.6	3.4
DeSoto: Waterborne Primer, Epoxy Powder Coating	11.0	3.9	9.9	5.0	11.3	9.6	11.4	8.2	5.4	4.8	5.2	5.5	7.6

that of primers, sealants, and topcoats. The controlling specification, MIL-C-81751, does require coating adhesion after an alloy steel test coupon is bent around a one-inch diameter mandrel. MCAIR has no reservations about the adhesion adequacy of Alseal 518 type coatings for internal surface applications.

d. Corrosion Resistance - A minimum corrosion resistance of 672 hours in a five-percent neutral salt fog environment was also required for the various protection systems applied to the cylinders. The 672-hour requirement was met with eight of the 10 protection systems (Table 9). Similar to the test panels, most of the salt fog duration times easily surpassed the 672 hour requirement. Figures 21 through 30 show the cylinders after 672 and 1344 hours of exposure. Table 9 lists hours of exposure through April 1990. Final salt fog duration results will be included in the proceedings for Phase III of the program.

The two protection systems that failed showed minute amounts of red rust in several small craters in the topcoat that extended to the primer. They appear to have resulted from either outgassing during an improper cure cycle, poor wetting, or contamination. Although these areas are so small that they are not visible in either Figure 28 or 30, they are indicative of the critical need for proper application of barrier-type protection systems.

D. SUPPORTING DATA

MCAIR had previously tested some of the materials used as protection systems and/or protection system components. Selection of these materials as candidate protection system materials was based on previous, positive experience with the material and/or material system.

o Alseal® 518 - MCAIR had demonstrated that Alseal 518 can be successfully applied to damaged IVD aluminum-coated steel panels. MCAIR also applied Alseal® 518 to an alloy steel panel, scribed it and exposed the panel to a five percent neutral salt fog environment for 9,000 hours without substrate

TABLE 9. CORROSION RESISTANCE OF SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO INTERNAL CYLINDER SURFACES IN A FIVE PERCENT NEUTRAL SALT FOG ENVIRONMENT.

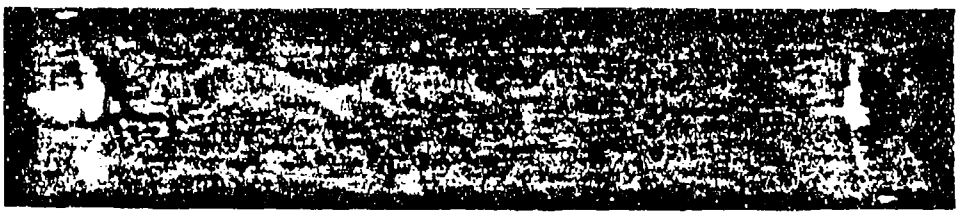
	Alloy Steel Cylinder Internal Surface ASTM-B117 Salt Fog Resistance	
Processor: Sacraficial Protection System	**672 hr**	**Duration**
MCAIR: Alseal 518	Passed	1,776[b]
MCAIR: Alseal 518, Waterborne Primer, Polyurethane Topcoat	Passed	1,344[b]
Processor: Barrier Type Protection System[a]		
MCAIR: Waterborne Primer, Polysulfide Sealant (Sprayed)	Passed	1,776[b]
MCAIR: Waterborne Primer, Polysulfide Sealant (Brushed)	Passed	2,208[b]
MCAIR: Waterborne Primer, Polysulfide Sealant (Fill and Drain)	Passed	2,208[b]
MCAIR: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat	Passed	2,208[b]
Embee Plating: Manganese Phosphate Epoxy Primer, Polyurethane Topcoat	Passed	1,776[b]
Embee/MCAIR: Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Topcoat	c	1,344[b]
DeSoto: Epoxy Primer, Epoxy Powder Coating	Passed	1,344[b]
DeSoto: Waterborne Primer, Epoxy Powder Coating	c	1,344[b]

a Although these systems are designated barriers, some component materials contain leachable compounds which provide some chemical protection – see Table 1.

b Cylinders are still in test.

c Topcoat contained several small craters extending to primer coat. Pencil-point areas of red rust in craters observed at 672 hours. Specimens left in test, with no additional degradation through noted duration.

Cylinder Corrosion Test Specimen



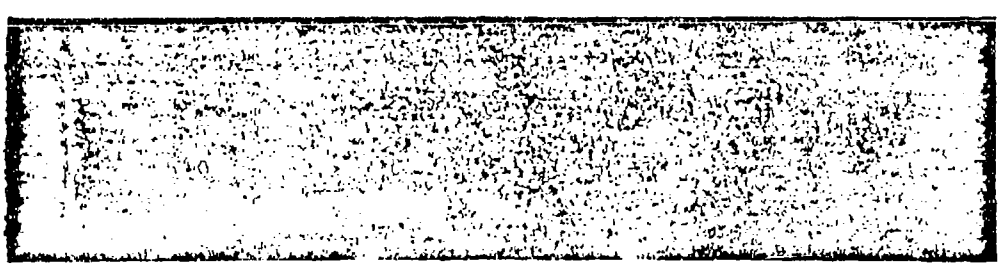
Alseal 518
672 Hours – 5% Neutral Salt Fog

Alseal 518
1,344 Hours – 5% Neutral Salt Fog

Figure 21. Corrosion Resistance: Alseal 518 Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen

Alseal 518, Waterborne Primer, Polyurethane Topcoat
672 Hours – 5% Neutral Salt Fog



Alseal 518, Waterborne Primer, Polyurethane Topcoat
1,344 Hours – 5% Neutral Salt Fog

Figure 22. Corrosion Resistance: Alseal 518, Waterborne Primer, Polyurethane Topcoat Protection System Applied to Cylinder Internal Surface.

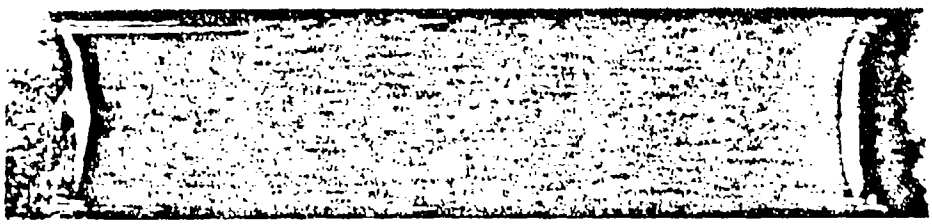
Cylinder Corrosion Test Specimen

Waterborne Primer, Polysulfide Sealant (Spray Applied)
672 Hours – 5% Neutral Salt Fog

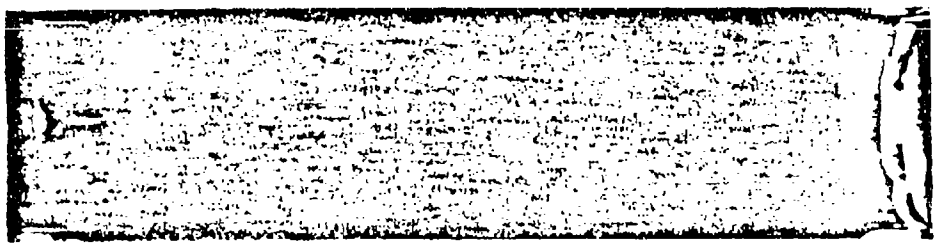
Waterborne Primer, Polysulfide Sealant (Spray Applied)
1,344 Hours – 5% Neutral Salt Fog

Figure 23. Corrosion Resistance: Waterborne Primer, Polysulfide Sealant (Sprayed) Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen



Waterborne Primer, Polysulfide Sealant (Brush Applied)
672 Hours – 5% Neutral Salt Fog

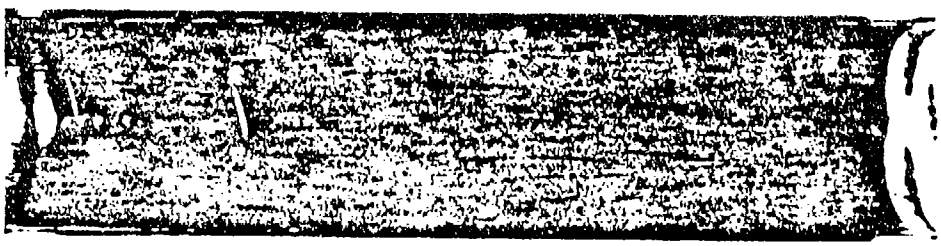


Waterborne Primer, Polysulfide Sealant (Brush Applied)
1,344 Hours – 5% Neutral Salt Fog

Figure 24. Corrosion Resistance: Waterborne Primer, Polysulfide Sealant (Brushed) Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen

Waterborne Primer, Polysulfide Sealant (Fill and Drain Applied)
672 Hours – 5% Neutral Salt Fog



Waterborne Primer, Polysulfide Sealant (Fill and Drain Applied)
1,344 Hours – 5% Neutral Salt Fog

Figure 25. Corrosion Resistance: Waterborne Primer, Polysulfide Sealant (Fill and Drain) Protection System Applied to Cylinder Internal Surface.

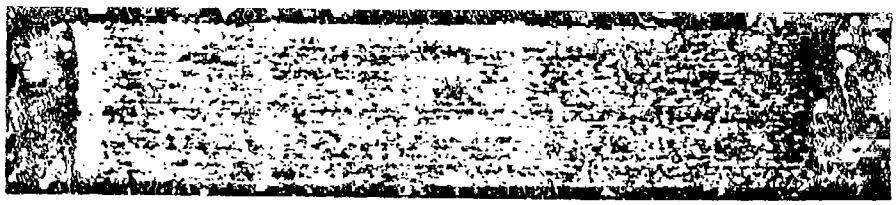
Cylinder Corrosion Test Specimen

Epoxy Primer, Polysulfide Sealant,
Polyurethane Enamel Topcoat
672 Hours – 5% Neutral Salt Fog

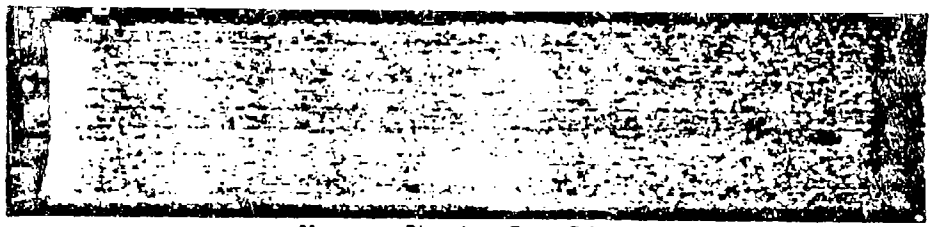
Epoxy Primer, Polysulfide Sealant,
Polyurethane Enamel Topcoat
1,344 Hours – 5% Neutral Salt Fog

Figure 26. Corrosion Resistance: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen



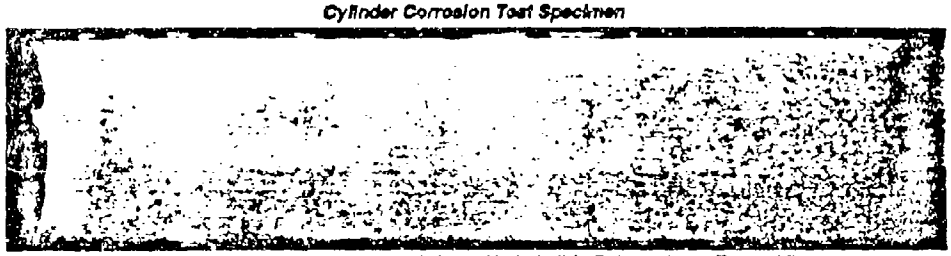
Manganese Phosphate, Epoxy Primer,
Polyurethane Enamel Topcoat
672 Hours – 5% Neutral Salt Fog



Manganese Phosphate, Epoxy Primer,
Polyurethane Enamel Topcoat
1,344 Hours – 5% Neutral Salt Fog

Figure 27. Corrosion Resistance: Manganese Phosphate, Epoxy Primer, Polyurethane Topcoat Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen

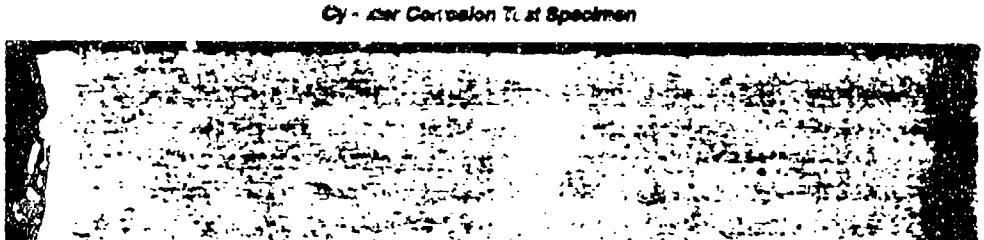


Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Enamel Topcoat
672 Hours – 5% Neutral Salt Fog

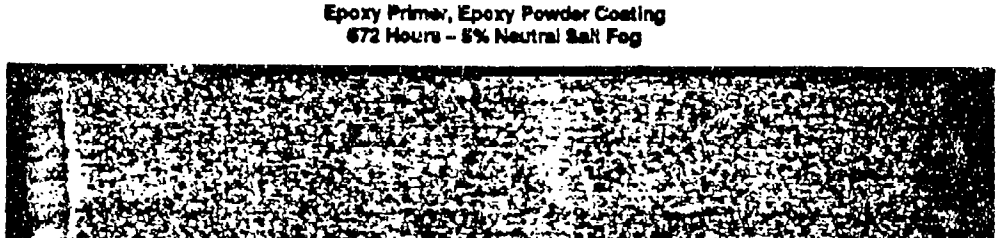
Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Enamel Topcoat
1,344 Hours – 5% Neutral Salt Fog

Figure 28. Corrosion Resistance: Manganese Phosphate, Waterborne Primer, High Solids Topcoat Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen



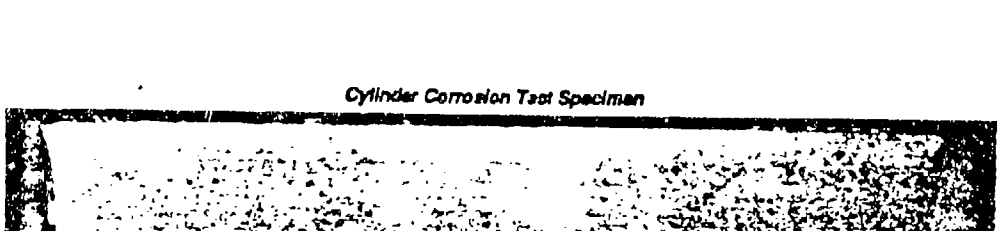
Epoxy Primer, Epoxy Powder Coating
672 Hours – 5% Neutral Salt Fog



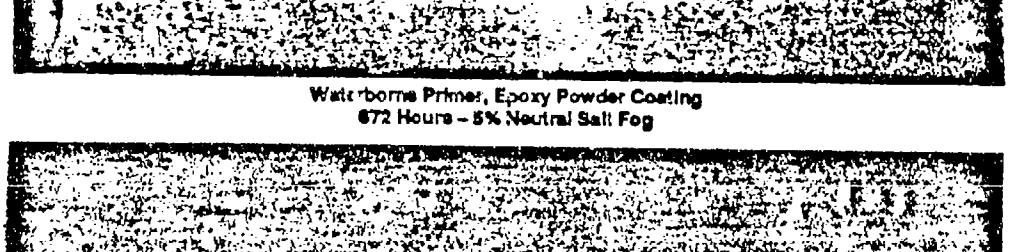
Epoxy Primer, Epoxy Powder Coating
1,344 Hours – 5% Neutral Salt Fog

Figure 29. Corrosion Resistance: Epoxy Primer and Epoxy Powder Coating Protection System Applied to Cylinder Internal Surface.

Cylinder Corrosion Test Specimen



Waterborne Primer, Epoxy Powder Coating
672 Hours – 5% Neutral Salt Fog



Waterborne Primer, Epoxy Powder Coating
1,344 Hours – 5% Neutral Salt Fog

Figure 30. Corrosion Resistance: Waterborne Primer and Epoxy Powder Coating Protection System Applied to Cylinder Internal Surface.

corrosion (red rust) (Reference 4). MCAIR also has an alloy steel panel coated with Alseal 518 in an outdoor exposure test in St. Louis. The panel has been in test for five years without red rust.

o Epoxy primer, polysulfide sealant, polyurathane topcoat - MCAIR originally tested the corrosion resistance of the "primer, sealant, and topcoat" on six 3- by 6-inch 4130 alloy steel panels (Reference 5) as a repair procedure. The panels had their paint and IVD aluminum coatings removed from a 0.5- by 1.0-inch area in the center of the panel and the "primer, sealant, and topcoat" repair applied. A diagonal line was scratched in the repair system on three panels. The panels were then subjected to the Naval Air Development Center (NADC) SO_2 salt-fog exposure test for 28 days without red rust. MCAIR then applied the "primer and sealant" protection system to the internal surfaces of a 2.5-inch diameter by 6.5-inch long alloy steel cylinder that was closed on one end. The cylinder was also exposed to the harsh NADC SO_2 salt fog environment for 56 days (28 days by MCAIR and 28 days by NADC) without substrate corrosion.

o Manganese phosphate, epoxy primer, polyurethane topcoat - This protection system is in production use on the Air Force F-15E Piston Assembly - Main Landing Gear, P/N 68A412704. This alloy steel detail part is protected with IVD aluminum coating on external surfaces and with the supplemental "phosphate, primer, topcoat" protection system on internal surfaces. This protection system has been used since 1986 with no known problems.

o Waterborne primers - MCAIR has demonstrated in thorough laboratory testing that the performance of low VOC, environmentally compliant waterborne primer per MIL-P-85582 exceeds that of currently used exempt solvent and higher VOC primers per MIL-P-23377.

MCAIR has issued paperwork that allows the use of waterborne primers to meet more stringent environmental regulations in such areas as California and Oklahoma.

o High-Solids Polyurethane Topcoat - MCAIR has also engaged in a thorough evaluation of environmentally compliant topcoats per MIL-C-85285 that are now beginning to replace higher VOC topcoats per MIL-C-83286. Our laboratory evaluation (References 6 and 7) identified several of the high-solids topcoat that met and/or exceeded the performance of the MIL-C-83286 standards.

o Powder Coating - MCAIR tested a Pratt and Lambert Powder Coating (Vitrolon 88-1103) to our in-house requirements for fluid resistance, flexibility, and corrosion resistance for polyurethane topcoats. The powder coating passed all the tests except the reverse impact flexibility test at -65°F (Reference 8).

E. DISCUSSION

MCAIR believes that the ALCs can currently implement the use of any of the Table 6 protection systems other than the two systems that include powder coatings. MCAIR believes that epoxy powder coatings will eventually be implemented by the aerospace industry as will as epoxy primers applied by electrocoating. These processes are commonly used on steel substrates in the industrial sector. They offer 98 percent transfer efficient and low VOC emission. MCAIR believes they are the best prospects for long-term environmental compliance.

MCAIR used Alseal 518 on the cylinders to represent all three of the metallic-ceramic type sacrificial coatings that were tested on panels; namely: Alseal® 518, Xylar® 1 and Sermetel® CR948-LT. These MIL-C-81517 aluminum-filled coatings are used on alloy steel detail by DoD agencies such as the ALCs on engine parts and the Naval Sea Systems Command on marine hardware. MCAIR limited the cure temperature of these coatings to 500°F because of potential use on high-strength steel landing gear components. Although 500°F is an adequate cure temperature, it is not high enough to produce an electrical conductive, sacrificial coating. The glass bead peening processing step (see Table 7) is required to assure a conductive coating.

MCAIR tested Alseal 518 by itself to demonstrate the adequacy of MIL-C-81751 coatings as stand-alone protection systems. In reality, the IVD aluminum - Alseal 518 combination would be painted with a primer and topcoat. Therefore, MCAIR also included a protection system comprised of Alseal 518, primer and topcoat.

MCAIR included both the commonly used mil-spec epoxy primers and polyurethane topcoats as well as newer, low VOC versions of epoxy primer and polyurethane topcoats. The waterborne epoxy primer meets the current California and other pending VOC limits of 350 grams/liter (g/l) for primers. The high-solids polyurethene formulation meets pending topcoat regulations of 420 g/l VOCs for topcoats. MCAIR also included both current and low VOC epoxy primers in conjunction with polysulfide sealant. Polysulfide sealant applied by the "brush" procedure easily meets VOC requirements for sealants (see Table 5). Polysulfide sealant applied by the "spray" and "fill & drain" procedures will be affected by pending regulations such as California Rule 1124 (see Table 5).

MCAIR included the epoxy primer, polysulfide sealant, polyurethane topcoat protection system because of existing MCAIR test data outlined in this section. MCAIR has also both used and recommended this protection system for field repair of damaged IVD aluminum coating.

MCAIR included the manganese phosphate, epoxy primer, polyurethane topcoat protection system which is in current production use on the internal surface on the F-15E main landing gear piston assembly. This landing gear detail is coated with IVD aluminum on external surfaces. MCAIR also included a version of this protection system with the more environmentally compliant primer and topcoat.

The question may be asked, "If a supplemental protection system is adequate for an internal surface, why not use that system over the entire component rather than in combination with IVD aluminum, thus eliminating two-step processing?" The answer is that what may be adequate for internal

surfaces may not be adequate for external surfaces. For example, the sacrificial aluminum-filled paint-type coatings provide excellent corrosion resistance and should be more than adequate to protect internal surfaces. However, internal surfaces are not normally subjected to the more harsh corrosive environments nor to the same harsh demands on coating adhesion as external surfaces. Therefore, the IVD aluminum process is recommended on all external surfaces and on as large a portion of the internal surfaces as possible. The reasons are that in addition to corrosion resistance, IVD aluminum provides superior coating adhesion and superior uniformity and coverage on part edges.

As an example, the external surfaces of landing gear details and turbine shafts are exposed to more harsh conditions than internal surfaces. The abrasive effects of take-offs and landings require a coating that adheres well and is resistant to chipping. The IVD aluminum coating does not chip; it is required that IVD coating adhesion pass the stringent bend-to-break coupon test. In contrast, the aluminum-filled paint type coatings are highly susceptible to the chipping type of nonadhesion. Typically, these coatings will not meet the bend-to-break adhesion requirement.

IVD aluminum also provides excellent coating uniformity and coverage on details in the transition area between external and internal surfaces. These areas often are threaded and/or contain sharp edges. IVD aluminum does not build up on or run off of sharp edges or thread crests/roots regardless of thickness. The paint and spray-type coatings will run off of edges and build up in recesses.

F. CONCLUSION

All of the various protection systems, both sacrificial and barrier type, that were applied to the internal surfaces of the alloy steel cylindrical details demonstrated good corrosion resistance characteristics. The protection systems also exhibited acceptable adhesion to the alloy steel substrates, and the various application methods provided acceptable thickness and uniformity.

Higher reliability may be obtained with the MIL-C-81751 coatings because of their sacrificial protection capabilities and with the barrier-type protection systems containing polysulfide sealant because of its flexibility.

Correct processing technique and procedure are critical, especially with the barrier-type protection systems. The potential effectiveness of these systems has been demonstrated with flat panels which are easy to process. At least one of these systems has been in production use for several years on a F-15E landing gear detail.

MCAIR believes that a two-step IVD aluminum plus supplement protection system approach offers an acceptable alternate to processing internal surfaces with cadmium.

SECTION IV
TORQUE-TENSION COMPARISONS

A. PROBLEM

Aluminum has a higher coefficient of friction than cadmium. Therefore, a higher torque is required to install aluminum-coated fasteners to a given tension preload than if the fastener was cadmium plated. Fasteners are often installed at particular torques that have been determined to give desired preloads. These torque values are usually required by the overhaul manuals supplied by the original equipment manufacturers (OEMs). The OEMs are naturally reluctant to approve plating substitutions that do not provide similar torque-tension characteristics. Although the difference in torque-tension characteristics between aluminum and cadmium is minimized by the use of lubricants (Reference 1), much of the data generated to date is for shear-type and non-highly loaded tension-type fastener systems. Additionally MCAIR generally uses IVD aluminum-coated bolts/screws with cadmium-plated nuts and generated most of their torque-tension characteristics with that combination.

The Ogden (OO) ALC and Bendix (an OEM) have identified wheel tie-bolts (Figure 31) as a major concern. Eight to 12 tie-bolts are typically used to bolt wheel-halves together on military aircraft. These high-strength alloy steel details are designed to be highly loaded - usually in the range of 60 to 75 percent of the ultimate strength of the fastener. The fastener system (nut and bolt) relies on the installation torque required by the overhaul manual to achieve designed loading. For most wheel tie-bolts, the torque values required by the overhaul manual are based on a hardware system plated with cadmium for corrosion resistance, and lubricated with MIL-T-5544 synthetic graphite - petrolatum prior to installation. There is no corresponding torque-tension data for this situation when the hardware is coated with IVD aluminum.

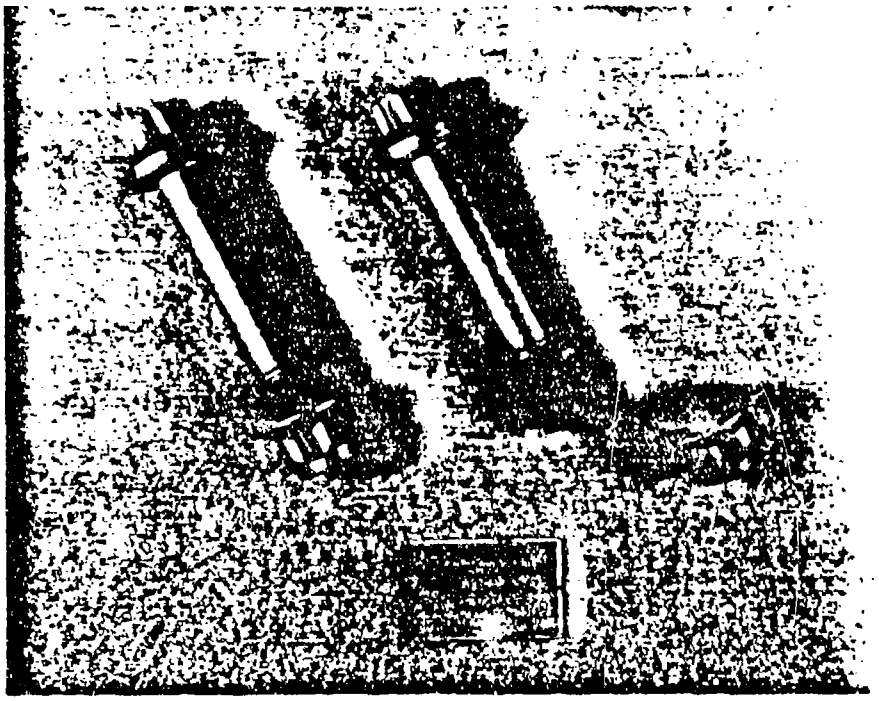


Figure 31. IVD Aluminum-Coated Wheel Tie-Bolt and Nut

The Oklahoma City (OC)-ALC, San Antonio (SA) ALC, and Allison (an OEM) have also expressed concern about the use of IVD aluminum on threaded hardware. The SA-ALC had asked Allison for concurrence to use IVD aluminum on T-56 engine details as a replacement for electroplated cadmium and diffused nickel-cadmium. Allison, in turn, gave concurrence (Reference 9) with the exception of threaded engine hardware. Their reluctance to use IVD aluminum on threaded hardware is based on a Pratt & Whitney (P&W) document (Reference 10). P&W reported that considerably more torque is required to load IVD aluminum-coated engine bolts than to load diffused nickel-cadmium plated bolts when lubricated with engine oil. Engine oil is a commonly used lubricant for engine bolts. The following Allison excerpt exemplifies their concern.

"A change in coatings changes the coefficient of friction thus affecting a torque required to achieve a given axial load. A significant change in torque requirements, as a result of IVD Aluminum, would be unacceptable since

production parts would continue to be coated with cadmium. It would be impractical and confusing to have two sets of torque values in assembly instructions and overhaul manuals. This author recommends that IVD aluminum not be used on the parts listed in Attachment 1." (threaded hardware).

B. SOLUTION/APPROACH

Document that the difference in torque-tension characteristics between IVD aluminum and cadmium is minimized by the use of lubricants for ALC wheel tie-bolts and threaded engine hardware.

Divide the effort into two tasks:

1. Wheel Tie-Bolts

Develop a generic torque-tension data base for lubricants now in use by the ALCs. Use additional lubricants if required to minimize torque-tension differences. At the conclusion of the generic testing, generate comparative data on actual tie-bolts using both the graphite - petrolatum lubricant now in use by OO-ALC and candidate lubricants identified as having a positive effect by the generic test. Generate data for 15 cycles of reuse which is the designed work-life before refurbishment of the wheel tie-bolts.

2. Threaded Engine Hardware

MCAIR met with OC-ALC to address this issue and coordinate a test program. The program was also coordinated with Allison.

Since other torque-tension (References 11 and 12) comparisons between IVD aluminum and diffused nickel-cadmium reported that torque-tension was essentially unaffected by any differences in the two finishes, it was decided to rerun the one test (Reference 10) that shows considerable differences. Several other factors that were considerations included the very early period of IVD aluminum development in which the Reference 10 data was generated and the possibility that too thick of an IVD aluminum coating was

tested. Additionally the hardware combination consisted of a diffused nickel-cadmium plated bolt and cadmium-plated nut rather than two diffused nickel-cadmium plated components.

C. DATA

1. Generic Torque-Tension Data

NAS1308-10 bolts supplied by Voi-Shan and 47FLW-820 nuts supplied by SPS were used to generate generic torque-tension data for wheel tie-bolts. Descriptions of the bolt and nut are shown in Tables 10 and 11, respectively.

TABLE 10. NAS1308-10 BOLT DESCRIPTION.

Bolt Description	Bolt Designation	Thread Size and Description	Bolt Length		Corrosion Preventive Finish	
			Grip (in.)	Total (in.)	Cadmium	IVD Aluminum
Shear, Hexagon Head, Ultimate Tensile Strength 160 – 180 ksi	NAS1308-10	0.5000-20 UNJF-3A	0.625	1.360	Per QQ-P-416, Type II, Class 2	Class 3, Type II Per MIL-C-83488

TABLE 11. 47FLW-820 NUT DESCRIPTION.

Nut Description	Nut Designation	Thread Size and Description	Nut Height (in.)	Corrosion Preventive Finish	
				Cadmium	IVD Aluminum
Flexloc, Tension Double Hexagon, Flanged, Self-Locking, Alloy Steel, 180 ksi, 450°F, Lightweight	47FLW-820	0.5000-20 UNJF-3B	0.549	Per QQ-P-416, Type II, Class 2	Class 3, Type II Per MIL-C-83488

Torque-tension and other installation data was generated for fifteen installation cycles of reuse for the various bolt finish - nut finish - lubricant combinations shown in Table 12. A description of each lubricant is shown in Table 13.

TABLE 12. BOLT FINISH – NUT FINISH – LUBRICANT COMBINATIONS EVALUATED DURING GENERATION OF GENERIC TORQUE-TENSION DATA.

Test No.[a]	Finish				Supplemental Lubrication			Lubricant
	Bolt		Nut		On IVD Aluminum Coated Bolt	On IVD Aluminum Coated Nut		
	Cadmium	IVD Aluminum	Cadmium[b]	IVD Aluminum		Carbowax[c]	Other	
1-3	X		X					C-601-S
3-6		X		X				C-601-S
7-10	X		X					C-601-S
11-13		X		X				C-601-S
14-17		X	X					C-601-S
18-22		X		X		X		C-601-S
23-26		X		X				C-601-S
27-29	X			X		X		C-601-S
30-36		X		X		X		C-601-S
37		X		X				C-601-S
38		X		X		X		C-601-S
39-41	X		X					C-670
42-44		X		X				C-670
45-47	X		X,,					Moly-50
48-50				X				Moly-50
51-53	X		X					Royco 81MS
54-56		X		X		X		Royco 81MS
57	X		X					GP-400
58		X		X		X		GP-400
59	X		X					GP-401
60		X		X		X		GP-401
61	X		X					GP-460
62		X		X		X		GP-460
63	X		X					CP-28
64		X		X		X		CP-28
65	X		X					CP-29
66		X		X		X		CP-29
67	X		X					CP-42
68		X		X		X		CP-42
69	X		X					Formkote T-50
70		X		X		X		Formkote T-50
71	X		X					Lubri-Bond A
72		X		X		X		Lubri-Bond A
73-75	X		X					CP-116
76-78		X		X		X		CP-116
79-81	X		X					MIL-T-83483
82-84		X		X		X		MIL-T-83483

TABLE 12. BOLT FINISH – NUT FINISH – LUBRICANT COMBINATIONS EVALUATED DURING GENERATION OF GENERIC TORQUE-TENSION DATA (CONCLUDED).

Test No.[a]	Finish				Supplemental Lubrication			Lubricant
	Bolt		Nut		On IVD Aluminum Coated Bolt	On IVD Aluminum Coated Nut		
	Cadmium	IVD Aluminum	Cadmium[b]	IVD Aluminum		Carbowax[c]	Other	
85		X		X				Formkote T-50 and C-601-S
86		X		X				Perma-Slik-S and C-601-S
87		X		X	X		X	Xylar 101 and C-601-S
88		X		X			X	Xylar 101 and C-601-S
89		X		X	X	X		Xylar 101 and C-601-S
90-91		X		X	X		X	Everlube 1346 and C-601-S
92-93		X		X	X		X	EM-6256 and C-601-S
94-95		X		X	X		X	EM-6286 and C-601-S
96-97		X		X			X	Everlube 1346 and C-601-S
98-99		X		X			X	EM-6256 and C-601-S
100-101		X		X			X	EM-6286 and C-601-S

a The data for each test is found in appendix A. The test number corresponds to the Appendix table number. (Example: Data for test number 1 is found in Appendix table A-1.).

b The cadmium nuts were supplied with Carbowax .

c The IVD aluminum-coated nuts were coated with Carbowax by either SPS Technologies or MCAIR.

TABLE 13. LUBRICANTS EVALUATED DURING GENERIC TORQUE-TENSION TESTING FOR WHEEL TIE-BOLTS.

Lubricant	Supplier[a]	Description	Applicable[b] Mil-Specs	Processor[c]
C-601-S	Fel-Pro Incorporated	Paste, Antiseize Thread Compound, Containing 50 Percent Synthetic Graphite and 50 Percent Petrolatum	MIL-T-5544	MCAIR
C-670	Fel-Pro Incorporated	Paste Containing 65 Percent Molybdenum Disulfide	None	MCAIR
Moly-50	Fel-Pro Incorporated	Paste, Antiseize Thread Compound, Containing 50 Percent Molybdenum Disulfide and 50 Percent Petrolatum	MIL-T-83483	MCAIR
Royco 81MS	Royal Lubricants Company Incorporated	Lubricating Grease, a Mixture Basically 50 Percent Molybdenum Disulfide and 50 Percent Silicone Oil	DOD-L-25681	MCAIR
GP-400	Graphite Products Company	Paste, Antiseize Lubricant, Containing Approximately 50 Percent Molybdenum Disulfide, 5 Percent Graphite, and 40 Percent Mineral Oil With a Soap Base Thickener	None	MCAIR
GP-401	Graphite Products Company	Paste, Antiseize Lubricant, Containing Approximately 50 Percent Molybdenum Disulfide, 5 Percent Graphite, and 40 Percent Mineral Oil With a Non Soap Base Thickener	None	MCAIR
GP-460	Graphite Products Company	Paste, Antiseize Thread Compound, Containing 50 Percent Synthetic Graphite and 50 Percent Petrolatum	MIL-T-5544	MCAIR
CP-28	E/M Corporation	Paste, Extreme Pressure Assembly Lubricant, Containing 60 Percent Molybdenum Disulfide, an Organic Barium Compound, Mineral Oil, and Lithium Grease	None	MCAIR
CP-29	E/M Corporation	Paste, Antiseize Lubricating Compound, Containing Molybdenum Disulfide, Finely Divided Copper Metal Particles, Silica, and Mineral Oil	None	MCAIR
CP-42	E/M Corporation	Paste Containing a High Concentration of Molybdenum Disulfide in a Synthetic Polyalkylene Glycol Base	None	MCAIR

TABLE 13. LUBRICANTS EVALUATED DURING GENERIC TORQUE -TENSION TESTING FOR WHEEL TIE-BOLTS (CONTINUED).

Lubricant	Supplier[a]	Description	Applicable Mil-Specs[b]	Processor[c]
Formkote T-50	E/M Corporation	A Dry, Solid Film Lubricant Containing a Composition of Lubricating Pigments, Graphite Being One, Suspended in a Modified High Temperature Resin Binder	None	MCAIR
Lubri-Bond A	E/M Corporation	An Air Drying, Solid Film Lubricant Containing Molybdenum Disulfide and Graphite in a Resin Binder	MIL-L-23398	MCAIR
CP-116	E/M Corporation	Paste, Antiseize Thread Compound, Containing Molybdenum Disulfide, Mineral Oil, and Petrolatum	MIL-T-83483	MCAIR
MIL-T-83483	Armite Laboratories	Paste, Anti-Seize Thread Compound, Containing 50 Percent Molybdenum Disulfide and 50 Percent Petrolatum	MIL-T-83483	MCAIR
Formkote T-50	E/M Corporation	See Formkote T-50 Above	None	MCAIR
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	MCAIR
Perma-Slik S	E/M Corporation	An Air Dried, Solid Film Lubricant Containing Molybdenum Disulfide in a Minimum Amount of Binder	None	MCAIR
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	MCAIR
Xylar 101	Whitford Corporation	Coating Contains Nonmetallic Fillers In Combination With Ceramic Materials to Extend the Performance of Aluminum Coatings	MIL-C-81751 Type I, Class 4	MCAIR
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	
Everlube 1346	E/M Corporation	An Air Cured, Bonded Solid Film Lubricant Formulated With Molybdenum Disulfide in a Resin Binder	None	E/M Corp
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	MCAIR
EM-6256	E/M Corporation	A Bonded Solid Film Lubricant Formulated With Molybdenum Disulfide to Produce Torque-Tension Characteristics Similar to Cadmium Electroplate Plus Wax	None	E/M Corp
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	MCAIR
EM-6286	E/M Corporation	A Bonded Solid Film Lubricant Formulated With Graphite in a Resin Binder	None	E/M Corp
and C-601-S	Fel-Pro Incorporated	See C-601-S Above	MIL-T-5544	MCAIR

TABLE 13. LUBRICANTS EVALUATED DURING GENERIC TORQUE-TENSION TESTING FOR WHEEL TIE-BOLTS (CONCLUDED).

Lubricant	Supplier[a]	Description	Applicable[b] Mil-Specs	Processor[c]
Carbowax	Union Carbide Chemicals and Plastics Company Inc	Polyethylene Glycol 3350, a Non Dry Lubricant (Wax Type) Applied to Cadmium Plated and IVD Aluminum-Coated Nuts to Reduce Galling and Seizing	None	SPS Technologies MCAIR

a Suppliers
- Fel-Pro Incorporated, Chemical Products Division, 7450 North McCormick Boulevard, P.O. Box 1205, Skokie, Illinois 60076-8205
- Royal Lubricants Company Inc, P.O.Box 518, 72 Eagle Rock Avenue, East Hanover, NJ 07367
- Graphite Products Company, P.O. Box 29, Brookfield, Ohio 44403
- E/M Corporation, P.O. Box 2400, 2801 Kent Avenue, West Lafayette, Indiana 47906
- Armite Laboratories, 1845 Randolph Street, Los Angeles, California 90001
- Whitford Corporation, P.O. Box 507, West Chester, Pennsylvania 19381
- Union Carbide Chemicals and Plastics Co Incorporated, Industrial Chemicals Division, 39 Old Ridgebury Road, Danbury, Connecticut 06817-0001

b Military Specifications
- MIL-T-5544 – Thread Compound, Antiseize, Graphite - Petrolatum
- MIL-T-83483 – Thread Compound, Antiseize, Molybdenum Disulfied – Petrolatum
- DOD-L-25681 – Lubricant Molybdenum Disulfide, Silicone
- MIL-L-23398 – Lubricant, Solid Film, Air-Cured,Corrosion inhibiting
- MIL-C-81751 – Coating, Metallic - Ceramic

c Processors
- McDonnell Aircraft Company (MCAIR), P.O. Box 516, St. Louis, Missouri 63166
- E/M Corporation, P.O. Box 2400, 2801 Kent Avenue, West Lafayette, Indiana 47906

The torque-tension data was generated by holding the bolt head fixed and rotating the nut. A GSE, Inc. Model FT-500 Fastener Force Transducer and 125 KSI hardened, chamfered washer were installed between the bolt head and nut. The "fastener force transducer" is a miniature load cell developed specifically for measurement of fastener clamping forces. The washer against the bolt head was installed with its chamfered side toward the bolt head to provide clearance for any fillet at the head and shaft interface. The test set-up (Figure 32) allowed the minimum bolt protrusion of 0.080 inch through the self-locking nut as required by Reference 13. It also prevented nut rotation to the end of the threads on the bolt.

The loads generated by the range of torques for the various Table 12 bolt finish - nut finish - lubricant combinations were recorded by a GSE, Inc. Model 233-D Digital Peak Indicator which is compatible to the GSE Inc.

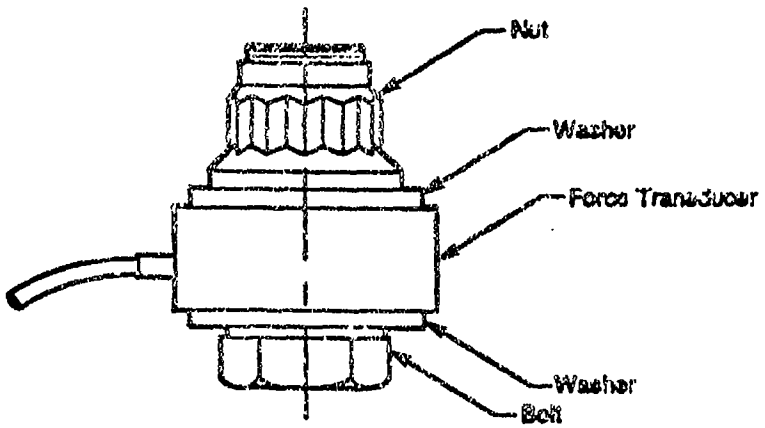


Figure 32. Test Setup Used to Generate Generic Torque-Tension Comparisons.

transducer. Three torque wrenches were used for the torque range to assure the most accurate, mid-range readings. All instrumentation was calibrated on a regular basis and is traceable to National Bureau Standards.

The fastener was loaded to 20,000 pounds during each installation cycle which is 70 percent of its ultimate strength. An example of the typical data generated for each 15-installation cycle evaluation is shown in Figure 33 and consists of:

o Bolt measurements - the shank of each bolt had its diameter and plating or coating thickness measured in three places prior to testing.

o Nut measurement - the plating or coating thickness was measured prior to testing.

o Lubricant information - the name of the lubricant, a brief description, and what it was applied to are listed.

o Running torque (loading cycle) - the maximum torque required to engage the locking feature of the self-locking nut was measured on the first,

fifth, tenth, and fifteenth loading cycles. The torque just prior to clampup of the test assemble was recorded.

o Torque-tension relationship - this relationship was established by recording the torque required for the specific range of tensile loads shown in Figure 33. The torque required to generate 10,000- and 20,000-pound loads was measured for all fifteen cycles. Additional torque amounts were recorded at 2,500-pound load increments for the first, fifth, tenth, and fifteenth installation cycles.

o Breakaway torque - the torque required to start nut rotation to relieve the 20,000-pound tensile bolt load was measured for the first, fifth, tenth, and fifteenth removal cycle.

o Running torque (removal cycle) - the minimum torque required to disengage the locking feature of the self-locking nut was measured on the first, fifth, tenth, and fifteenth removal cycle. This torque was recorded when a minimum of one and a maximum of two bolt threads extended beyond the nut.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
XX	1	100	190	295	415	555	725	875	1,025	1,225	950	90
	2					450				1,250		
	3					400				1,150		
	4					375				1,050		
	5	30	110	195	285	390	525	725	925	1,175	900	20
	6					350				1,200		
	7					380				1,150		
	8					365				1,050		
	9					355				1,000		
	10	30	85	165	250	345	460	625	800	975	650	20
	11					335				1,000		
	12					350				975		
	13					380				975		
	14					350				950		
	15	20	80	155	235	330	460	600	775	900	540	15

a The lubricant was applied to the threads of the bolt and nut.

b E/M Corporation CP-42 lubricant is a paste with a synthetic polyalkylene glycol fluid base containing a high concentration of molybdenum disulfide.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00037 in.

Figure 33. Example of Installation Data Generated for Typical 15-Cycle Reuse Evaluation.

Wet lubricants (no cure required) were brush applied to the threaded areas of the nuts and bolts. Only a thin film of lubricant was applied as any excess is squeezed out during tightening of the nut. The wet lubricants were removed with clean cheesecloth and/or solvent and reapplied for each installation. The dry lubricants (cure required) were applied only before the first installation cycle.

The same bolt-nut combination was used for all 15 installation cycles or until termination of a particular 15-cycle evaluation. The same fastener force transducer was used and its calibration was verified to be correct throughout the evaluation. Torque-tension and related installation data was generated for 101 15-cycle evaluations. It is located in Appendix A.

The torque-tension relationships between IVD aluminum and cadmium-finished wheel tie-bolt type hardware is summarized as follows:

a. With MIL-T-5544 synthetic graphite - petrolatum

MCAIR generated an extensive amount of data associated with the use of MIL-T-5544 synthetic graphite - petrolatum lubricants. It is currently required to be applied to wheel tie-bolts and nuts by virtually every applicable overhaul manual.

MCAIR obtained the best MIL-T-5544 lubricant results with the Fel-Pro, Inc. C-601-S lubricant. Its evaluation was recommended by Bendix (an OEM). Data generated for cadmium-plated hardware with C-601-S lubrication is used as baseline data. The torque required to produce a 20,000-pound tensile load for IVD aluminum and cadmium-finished hardware is compared in Table 14. This data shows that in order to obtain a 20,000-pound load:

- Approximately 30 percent more torque is required to load the IVD aluminum-coated hardware during the first installation cycle than to load the cadmium-plated hardware.

o The difference drops to about fifteen percent for the third cycle.

o The difference drops below 10 percent by the seventh installation cycle and stays between three and eight percent through the fifteenth cycle.

TABLE 14. TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD FOR IVD ALUMINUM- AND CADMIUM-FINISHED HARDWARE USING FEL-PRO C-601-S SYNTHETIC GRAPHITE – PETROLATUM LUBRICANT (MIL-T-5544).

Inst'l Cycle	Cd Bolt and Cd Nut	IVD Al Bolt and IVD Al Nut	% Increase Over Cd-Cd Baseline
1	645	837	29.8
2	663	809	22.0
3	675	774	14.7
4	675	766	13.5
5	669	767	14.7
6	663	739	11.5
7	675	727	7.7
8	675	716	6.1
9	669	718	7.3
10	669	723	8.0
11	663	709	6.9
12	656	689	5.0
13	650	693	6.6
14	650	673	3.5
15	663	703	6.0

MCAIR evaluated a number of variables introduced with the use of the C-601-S lubricant in an attempt to lessen the Table 14 "baseline" difference between IVD aluminum and cadmium. Special attention was given to the first several installation cycles where the difference is more pronounced. These variables are listed in Table 15 along with a brief result summary.

TABLE 15. VARIABLES EXAMINED DURING TORQUE-TENSION TESTS ON GENERIC BOLT AND NUT USING FEL-PRO, INC. C-601-S LUBRICANT.

Test No.[a]	Finish				Effect of Test Variable(s)	Results in Relation to Torque Required to Generate 20,000 lb Load
	Bolt		Nut			
	Cd	IVD Al	Cd[b]	IVD Al		
1 – 3	X		X		None	Established as Original Cadmium Baseline for Comparison.
4 – 6		X		X	None	Established as Original IVD Aluminum Baseline for Comparison.
7	X		X		Loading Bolt to 20,000 lb in Two Steps, 10,000 and 20,000 Pounds vs 2,500 pound steps.	No Effect at 20,000 Pounds. The Torque-Tension Curve Had Distinct Break at 10,000 Pounds When Bolt Was Loaded in Two Steps. A Smooth Torque-Tension Curve Was Obtained When Bolt Was Loaded in 2,500 Pound Steps. Retained Procedure to Briefly Stop at Each 2,500 Pound Load Increment to Record Torque.
8 – 10	X		X		Selection of Torque Wrenches.	Data Accuracy Improved. Established as New Cadmium Baseline.
11 – 13		X		X	Test Variables Were the Same as in Tests 8 – 10.	Result Was the Same as in Tests 8 – 10. Established as New IVD Aluminum Baseline.
14 – 17		X	X		Different Bolt and Nut Finishes.	Improvement Over IVD Aluminum Baseline.
18 – 21		X		X	Supplemental Lubricant, Carbowax on Nut.	Improvement Over IVD Aluminum Baseline for 1st Cycle.
22		X		X	Excess Amount of C-601-S Lubricant Applied to Either the Bolt and/or Carbowaxed Nut.	No Appreciable Effect.
23 – 26		X		X	Bolt Loaded to 20,000 Pounds With and Without Intermediate Stops.	No Appreciable Effect.
27 – 29	X			X	Different Bolt and Nut Finishes.	Improvement Over IVD Aluminum Baseline.
30		X		X	Lubricant Absorption into a More Open, Non-Peened Aluminum Coating.	No Appreciable Effect.

a The data for each test is found in Appendix A. The test number corresponds to the Table number. (Example: Data for Test Number 1 is found in Table A-1.).

b The cadmium nuts were supplied with Carbowax (Polyethylene Glycol 3350), a wax type lubricant. Carbowax is applied to non-dry film lubricated cadmium plated nuts by SPS Technologies to reduce galling and seizing.

TABLE 15. VARIABLES EXAMINED DURING TORQUE-TENSION TESTS ON GENERIC BOLT AND NUT USING FEL-PRO, INC. C-601-S LUBRICANT (CONTINUED).

Test No.[a]	Finish				Effect of Test Variable(s)	Results in Relation to Torque Required to Generate 20,000 lb Load
	Bolt		Nut			
	Cd	IVD Al	Cd[b]	IVD Al		
31		X		X	Polished Coating on Bolt and Nut.	No Appreciable Effect.
32		X		X	Thin Coating on the Bolt.	No Appreciable Effect.
33		X		X	Thin Coating on the Bolt and Ultrasonic Cleaning the Bolt and Nut After the First Cycle to Remove Any Metal Particles.	No Appreciable Effect.
34		X		X	Multiple Applications of Carbowax on the Bolt and Nut.	No Appreciable Effect.
35 – 36		X		X	Thin Coating on the Bolt and Nut and Ultrasonic Cleaning the Bolt and Nut After the First Cycle.	No Appreciable Effect.
37 – 38		X		X	Aluminum-Zinc Alloy Coating on the Bolt and Nut With and Without Carbowax.	No Appreciable Effect.
90 – 91		X		X	Supplumental Lubricant Coating, E/M Corporation Everlube 1346, on Bolts and Nuts.	Reduced the Higher Torques Noted With IVD Aluminum-Coated Bolts and Nuts During the First Few Installation Cycles in Relation to Cadmium.
92 – 93		X		X	Supplemental Lubricant Coating, E/M Corporation EM-6256, on Bolts and Nuts.	Reduced the Higher Torques Noted With IVD Aluminum-Coated Bolts and Nuts During the First Few Installation Cycles in Relation to Cadmium.
94 – 95		X		X	Supplemental Lubricant Coating, EM Corporation EM-6286, on Bolts and Nuts.	Reduced the Higher Torques Noted With IVD Aluminum-Coated Bolts and Nuts During the First Few Installation Cycles in Relation to Cadmium.

a The data for each test is found in Appendix A. The test number corresponds to the Table number. (Example: Data for Test Number 1 is found in Table A-1.).

b The cadmium nuts were supplied with Carbowax (Polyethylene Glycol 3350), a wax type lubricant. Carbowax is applied to non-dry film lubricated cadmium plated nuts by SPS Technologies to reduce galling and seizing.

TABLE 15. VARIABLES EXAMINED DURING TORQUE-TENSION TESTS ON GENERIC BOLT AND NUT USING FEL-PRO, INC. C-601-S LUBRICANT (CONCLUDED).

Test No.[a]	Finish				Effect of Test Variable(s)	Results in Relation to Torque Required to Generate 20,000 lb Load
	Bolt		Nut			
	Cd	IVD Al	Cd[b]	IVD Al		
96 – 97		X		X	Suplemental Lubricant Coating, E/M Corporation Everlube 1346, Applied Only to the Nut.	Comparable to Cadmium-Plated Baseline for the 5-Cycle Test.
98 – 99		X		X	Supplemental Lubricant Coating, E/M Corporation EM-6256, Applied Only to the Nut	Comparable to Cadmium-Plated Baseline for the 5-Cycle Test.
100 – 101		X		X	Supplemental Lubricant Coating, E/M Corporation EM-6286, Applied Only to the Nut.	Comparable to Cadmium-Plated Baseline for 5-Cycle Test.

a. The data for each test is found in Appendix A. The test number corresponds to the Table number. (Example: Data for Test Number 1 is found in Table A-1.).

b. The cadmium nuts were supplied with Carbowax (Polyethylene Glycol 3350), a wax type lubricant. Carbowax is applied to non-dry film lubricated cadmium plated nuts by SPS Technologies to reduce galling and seizing.

The following variables produced the most positive data and are discussed in more detail:

- Use of a cadmium-plated nut with the IVD aluminum-coated bolt
- Use of "supplemental" carbowax lubricant
- Use of "supplemental" dry-film lubricants

The combination of IVD aluminum-coated bolts and cadmium-plated nuts is a probability at most of the ALCs. Wheel tie-bolt hardware is refurbished after so many installations and/or by a maintenance schedule. During refurbishment, the bolts usually have their protective finish removed to be inspected and are then refinished at the ALC. They would be refinished

with IVD aluminum assuming the elimination of cadmium processing at the ALCs. The nuts, however, are usually scrapped due to locking feature wear after repeated installations. Replacement nuts ordered to existing drawings will likely be finished with cadmium for the immediate future.

Table 16 compares the torque-tension relationship of an IVD aluminum coated bolt - cadmium plated nut combination to the cadmium-plated baseline data. In order to obtain a 20,000-pound load:

- Basically the same torque is required to load both the IVD aluminum coated bolt - cadmium plated nut combination and the cadmium-plated combination for the first installation cycle.

- The difference increases to about 10-12 percent for the IVD aluminum - cadmium combination for the next five cycles.

- The difference then decreases to about 0-3 percent for the seventh through the fifteenth cycle.

TABLE 16. EFFECT ON TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD WHEN USING A CADMIUM-PLATED NUT WITH AN IVD ALUMINUM-COATED BOLT IN ADDITION TO C-601-S LUBRICANT.

Inst'l Cycle	Cd Bolt and Cd Nut	IVD Al Bolt and Cd Nut	% Increase Over Cd-Cd Baseline
1	645	650	0.8
2	663	742	11.9
3	675	750	11.1
4	675	758	12.3
5	669	750	12.1
6	663	725	9.4
7	675	692	2.5
8	675	683	1.2
9	669	675	0.9
10	669	683	2.1
11	663	667	0.6
12	656	667	1.7
13	650	667	2.6
14	650	658	1.2
15	663	667	0.6

MCAIR then determined the effect of applying Carbowax to the IVD aluminum-coated nut prior to applying the C-601-S lubricant. Carbowax is a wax-type lubricant that SPS Technologies applies to standard, cadmium-plated locknuts like the 47FLW-820 test nut unless otherwise specified. It is used to reduce galling and seizing (Reference 14).

Carbowax did lessen the torque required for the IVD aluminum-coated combination in the first installation from about 30 percent to 21 percent. The torque required for subsequent cycles was about the same as that for IVD aluminum without carbowax (Table 14). The torque-tension comparison to the cadmium-plated hardware baseline is shown in Table 17.

TABLE 17. EFFECT ON TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD WHEN USING CARBOWAX AS A SUPPLEMENTAL LUBRICANT IN ADDITION TO C-601-S. LUBRICANT.

Inst'l Cycle	Cd Bolt and Cd Nut	IVD Al Bolt and IVD Al Nut[a]	% Increase Over Cd-Cd Baseline
1	645	782	21.2
2	663	811	22.3
3	675	782	15.9
4	675	771	14.2
5	669	761	13.8
6	663	750	13.1
7	675	743	10.1
8	675	736	9.0
9	669	725	8.4
10	669	725	8.4
11	663	714	7.7
12	656	704	7.3
13	650	714	9.8
14	650	704	8.3
15	663	711	7.2

a Carbowax applied to nut only

MCAIR obtained good results with a group of three dry-film supplemental lubricants recommended by the E/M Corp for this type of application. The lubricants have either a graphite or a molybdenum disulfide base as described in Table 13. The torque-tension characteristics of IVD aluminum-coated hardware that had these lubricants applied and then topcoated with C-601-S synthetic graphite compared favorably with the cadmium-plated-hardware baseline. In general, the most favorable results occurred before the dry-film lubricant began to wear off. Torque-tension differences did increase slightly in the last eight installation cycles or so and basically provided the same results for these cycles as IVD aluminum without the supplemental lubricant.

MCAIR also evaluated E/M Corp. supplemental lubricants applied only to the IVD aluminum-coated nuts for five installation cycles. Once again, torque-tension characteristics compared favorably. The data indicates that treatment of the nut with only the supplemental lubricant is adequate.

The comparison of IVD aluminum to cadmium-finished hardware when using Everlube 1346 as a supplemental 601 is shown in Table 18. It shows that to obtain a 20,000-pound load in the aluminum-coated hardware:

- o About eight percent more torque is required during the first installation cycle.
- o The difference is basically within five percent for the next 10 cycles.
- o The difference increases to about 7-10 percent for the last five cycles. This compares with the results of C-601-S only on the IVD aluminum-coated hardware (Table 14) and indicates wear removal of the Everlube 1346.

TABLE 18. EFFECT ON TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD WHEN USING EVERLUBE 1346 AS A SUPPLEMENTAL LUBRICANT IN ADDITION TO C-601-S LUBRICANT.

Inst'l Cycle	Cd Bolt [a] and Cd Nut	IVD Al Bolt [b] and IVD Al Nut	% Increase Over Cd-Cd Baseline	IVD Al Bolt [c] and IVD Al Nut	% Increase Over Cd-Cd Baseline
1	645	700	8.5	750	16.3
2	663	650	(2.0)	675	1.8
3	675	650	(3.7)	650	(3.7)
4	675	650	(3.7)	650	(3.7)
5	669	675	0.9	663	(0.9)
6	663	713	6.0		
7	675	675	–		
8	675	675	–		
9	669	675	0.9		
10	669	700	4.6		
11	663	700	4.6		
12	656	700	6.7		
13	650	700	7.7		
14	650	713	9.7		
15	663	713	7.5		

a Lubricated with C-601-S only.
b IVD bolt and IVD nut both lubricated with E/M Corp. Everlube EM-1346 prior to application of C-601-S.
c IVD nut only lubricated with E/M Corp. Everlube EM-1346 prior to application of C-601-S.

The comparison of IVD aluminum- to cadmium-finished hardware when using Everlube EM-6256 as a supplemental lubricant is shown in Table 19. It shows that to obtain a 20,000-pound load in the IVD aluminum-coated hardware:

- Less than five percent more torque is required for the first five installation cycles.

- The differences increases to a maximum of about 15 percent in the thirteenth cycle before decreasing to about 11 percent for the fifteenth cycle.

TABLE 19. EFFECT ON TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD WHEN USING EVERLUBE EM-6256 AS A SUPPLEMENTAL LUBRICANT IN ADDITION TO C-601-S LUBRICANT.

Inst'l Cycle	Cd Bolt [a] and Cd Nut	IVD Al Bolt [b] and IVD Al Nut	% Increase Over Cd-Cd Baseline	IVD Al Bolt [c] and IVD Al Nut	% Increase Over Cd-Cd Baseline
1	645	663	2.7	688	6.6
2	663	675	1.8	625	(5.8)
3	675	675	–	605	(11.6)
4	675	675	–	595	(11.9)
5	669	700	4.6	598	(10.6)
6	663	738	11.3		
7	675	700	3.7		
8	675	725	7.4		
9	669	725	8.4		
10	669	725	8.4		
11	663	763	13.1		
12	656	750	14.6		
13	650	750	15.4		
14	650	725	11.5		
15	663	738	11.3		

a Lubricated with C-601-S only.

b IVD bolt and IVD nut both lubricated with E/M Corp. Everlube EM-6286 prior to application of C-601-S.

c IVD nut only lubricated with E/M Corp. Everlube EM-6286 prior to application of C-601-S.

The comparison of IVD aluminum- to cadmium-plated hardware when using EM-6286 as a supplemental lubricant is shown in Table 20. It shows that to obtain a 20,000-pound load in the IVD aluminum-coated hardware:

- About eight percent more torque is required in the first installation cycle.

- The difference is basically less than five percent for the second through the tenth cycle.

- The difference increases to a maximum of 10 percent during the last five cycles. This also compares with the results of C-601-S only on the IVD aluminum-coated hardware (Table 14) which indicates wear removal of the EM-6286.

TABLE 20. EFFECT ON TORQUE (INCH-POUNDS) REQUIRED TO PRODUCE 20,000-POUND LOAD WHEN USING EVERLUBE EM-6286 AS A SUPPLEMENTAL LUBRICANT IN ADDITION TO C-601-S LUBRICANT.

Inst'l Cycle	Cd Bolt [a] and Cd Nut	IVD Al Bolt [b] and IVD Al Nut	% Increase Over Cd-Cd Baseline	IVD Al Bolt [c] and IVD Al Nut	% Increase Over Cd-Cd Baseline
1	645	700	7.9	650	0.8
2	663	663	–	625	(5.7)
3	675	675	–	613	(9.2)
4	675	688	1.9	613	(9.2)
5	669	700	4.6	613	(8.4)
6	663	763	13.1		
7	675	713	5.6		
8	675	700	3.7		
9	669	700	4.6		
10	669	700	4.6		
11	663	700	5.6		
12	656	700	6.7		
13	650	713	9.7		
14	650	713	9.7		
15	663	725	9.4		

a Lubricated with C-601-S only.

b IVD bolt and IVD nut both lubricated with E/M Corp Everlube EM-6286 prior to application of C-601-S.

c IVD nut only lubricated with E/M Corp Everlube EM-6286 prior to application of C-601-S.

Similar patterns were observed for all three supplemental lubricants when applying them to the IVD aluminum-coated nuts only. The initial torque ranged from 1-16 percent higher in relation to the cadmium-plated-hardware baseline but dropped to values ranging from two percent higher to 12 percent lower for the next four cycles.

Figure 34 presents an overview of the torque-tension characteristics associated with the various factors tested with the use of C-601-S lubricant. It shows:

o The basic difference between IVD aluminum- and cadmium-finished hardware.

o A positive effect in relation to cadmium-finished baseline when using either of the following:

- Cadmium-plated nut with IVD aluminum-coated bolt

- Everlube 1346 applied to the IVD aluminum-coated bolt and nut as a supplement to C-601-S

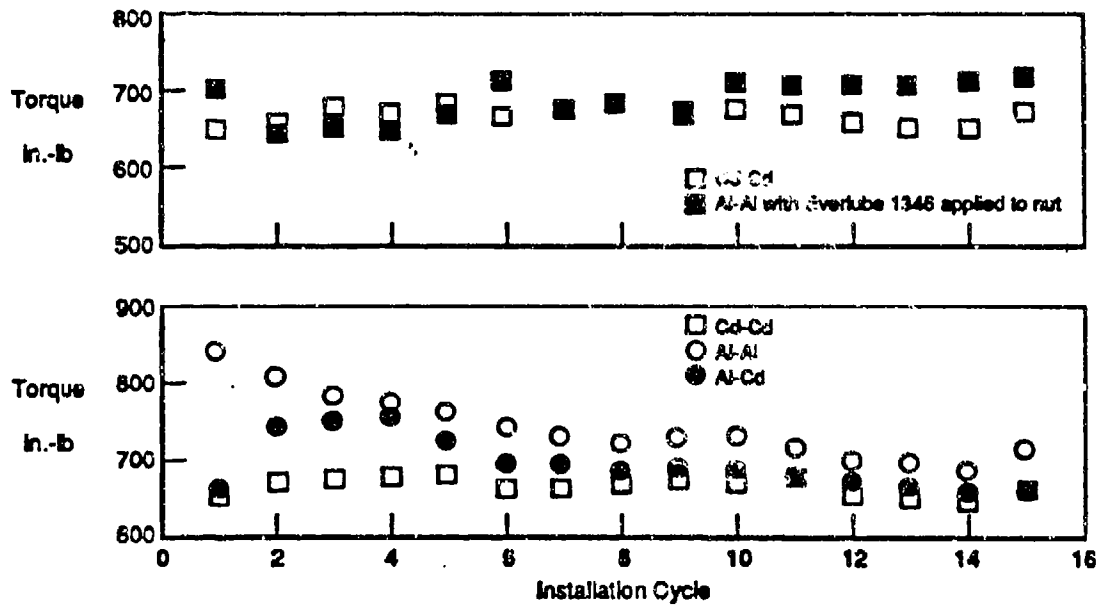


Figure 34. Torque Required to Generate 20,000-Pound Axial Load.

b. With MIL-T-83483 molybdenum disulfide - petrolatum

MCAIR generated data for three different MIL-T-83483 lubricants. Although not widely used by the ALCs, its usage is allowed as an option to MIL-T-5544 by OEMs like Bendix for some wheel tie-bolts. The combined torque-tension characteristics are shown in Table 21. The torque

TABLE 21. TORQUE (INCH-POUNDS) REQUIRED TO PROVIDE 20,000-POUND LOAD FOR IVD ALUMINUM- AND CADMIUM-FINISHED HARDWARE USING MIL-T-83483 MOLYDENUM DISULFIDE – PETROLATUM LUBRICANT.

Inst'l Cycle	Cd Bolt and Cd Nut	IVD Al Bolt and IVD Al Nut	Percent Increase Over Cd-Cd
1	686	828	20.7
2	681	819	20.3
3	678	808	19.2
4	672	783	16.5
5	663	765	15.4
6	664	767	15.5
7	667	731	10.0
8	659	722	9.6
9	659	703	6.7
10	638	690	8.2
11	649	681	4.9
12	645	680	5.4
13	636	675	6.1
14	626	672	7.3
15	620	666	7.4

required to produce a 20,000-pound tensile load in the IVD aluminum- and cadmium-finished hardware is compared in Table 21. The recorded torques for each installation cycle is the average of nine data points for each finish and combines the various MIL-T-83483 lubricants. In order to obtain a 20,000-pound load:

- Approximately 21 percent more torque is required to load the IVD aluminum-coated hardware during the first installation cycle than to load the cadmium-plated hardware.

- The difference drops to about 15 percent for the fifth cycle.

- The difference is below 10 percent for the eighth through fifteenth cycles.

The data generated for the Fel-Pro Inc., Moly-50 and E/M Corp., CP-116 MIL-T-83483 lubricants was similar. Both the IVD aluminum and cadmium-finished hardware lubricated with Armite Laboratories MIL-T-83483 require torque amounts ranging up to 10 percent higher than that required for

the other two. Individual data sheets are located in Appendix A. The Table 21 data compares very closely to the data generated with the MIL-T-5544 lubricant shown in Table 14.

c. With other lubricants

MCAIR did not find any other lubrication that performed as well by itself as the baseline MIL-T-5544 synthetic graphite - petrolatum lubricant other than the MIL-T-83483 molybdenum disulfide - petrolatum lubricant. There was no intention to recommend a change from the basic lubricants in use unless required. Therefore, the performance of the additional lubricants that were tested is not discussed here. However, torque-tension and other installation data is located in Appendix A for all the bolt finish - nut finish - lubricant combinations that are listed in Table 12.

2. Wheel Tie-Bolt Torque-Tension Data

The OO-ALC/MMILBE (F. O. Zvech) provided MCAIR with information on four ALC wheel tie-bolt and nut applications to generate data. After obtaining the hardware, MCAIR replaced the cadmium finish on half of it with IVD aluminum. A description of the bolts and nuts is given in Tables 22 and 23, respectively.

MCAIR recorded torque-tension characteristics to establish a baseline consisting of cadmium-plated bolts and nuts lubricated with C-601-S MIL-T-5544 synthetic graphite. MCAIR then compared IVD aluminum-coated hardware to the cadmium-plated baseline. Additional comparisons were generated for combinations consisting of:

o IVD aluminum-coated bolts and cadmium-plated nuts. This combination not only compared favorably in relation to the cadmium-plated baseline in the generic test but is also the most probable ALC combination.

o IVD aluminum-coated bolt and IVD aluminum-coated nut with the nut treated with a supplemental lubricant prior to the application of the

TABLE 22. DESCRIPTION OF WHEEL TIE-BOLTS.

Bolt Description	Bolt Designation	Thread Size and Description	Bolt Length		Corrosion Preventive Finish	
			Grip (in.)	Total (in.)	Cadmium	IVD Aluminum
Twelve Point External Wrenching – 180,000 psi	NAS632-18	0.7500-16 UNJF-3A	1.125	2.118	Fluoborate Plate Per NAS672	Class 3, Type II, Per MIL-C-83488
Wheel, Tension, Flanged, Steel, 180 ksi, F_{tu}, 450°F, External Wrenching	GY1810-36 (Goodyear)	0.625-18 UNJF-3A	2.250	3.19	Fluoborate Plate Per NAS672	Class 3, Type II, Per MIL-C-83488
Wheel, Tension, Flanged, Steel, 220 ksi, F_{tu}, 450°F, External Wrenching, Spline Drive	MS14163-09048	0.5625-18 UNJF-3A	3.000	4.025	Vacuum Deposited Per MIL-C-8837 Type II, Class 2	Class 3, Type II, Per MIL-C-83488
Tension, Steel, External Wrenching, Flanged, 12 Point, 180 ksi, 450°F	MS21250-05016	0.3125-24 UNJF-3A	1.000	1.645	Plate Per QQ-P-416, Type II, Class 2	Class 3, Type II, Per MIL-C-83488

TABLE 23. DESCRIPTION OF WHEEL TIE-BOLT NUTS.

Nut Description	Nut Designation	Thread Size and Description	Nut Height (in.)	Corrosion Preventive Finish	
				Cadmium	IVD Aluminum
Flexloc, Tension, Double Hexagon, Flanged, Self-Locking, Alloy Steel, 180 ksi, 450°F, Lightweight	47FLW-1216 (SPS Tech)	0.7500-16 UNJF-3B	0.750	Plate Per QQ-P-416, Type II, Class 2	Class 3, Type II, Per MIL-C-83488
Flexloc, Tension, Double Hexagon, Flanged, Self-Locking, Alloy Steel, 180 ksi, 450°F, Lightweight	47FLW-1018 (SPS Tech)	0.6250-18 UNJF-3B	0.650	Plate Per QQ-P-466, Type II, Class 2	Class 3, Type II, Per MIL-C-83488
Spline Drive, Flanged, Self-Locking, Alloy Steel, 220 ksi, 0.562-18	79502-918	0.562-18 UNJF-3B	0.585 – 0.600	Plate Per QC-P-416, Type II, Class 2	Class 3, Type II, Per MIL-C-83488
Flexloc, Tension, Double Hexagon, Flanged, Self-Locking, Alloy Steel, 180 ksi, 450°F, Lightweight	42FLW-524 (SPS Tech)	0.3125-24 UNJF-3B	0.363	Plate Per QQ-P-416, Type I, Class 3	Class 3, Type II, Per MIL-C-83488

C-601-S lubricant. This combination lessened torque-tension differences between IVD aluminum and cadmium in the generic test for the first several installation cycles where differences are most pronounced.

The test set-up is the same as that described for Figure 32 except spacers were used as required to compensate for bolt length. Figure 35 exemplifies spacer use. A GSE, Inc. Model FT-312 Fastener Force Transducer was used for the 5/16-inch diameter bolts and a Model FT-750 transducer was used for the 9/16-, 5/8-, and 3/4-inch diameter bolts. Additional spacers were used to center the 9/16- and 5/8-inch diameter bolts within the transducer. The same two transducers were used as applicable to generate all of the data and their calibration was verified to be correct throughout the evaluation.

The data generated for each set of wheel tie-bolt hardware is located in Appendix B and consists of the same information outlined in Figure 33 except the torque-tension relationship was established by recording the load generated by the required installation torque for each of the four different size bolts.

a. For the 3/4-inch diameter hardware

The torque-tension comparisons generated for the 3/4-inch diameter tie-bolt show that the load generated by a torque of 2100 inch-pounds decreases for IVD aluminum-coated hardware by 10-17 percent in relation to the cadmium-plated baseline (Table 24).

The use of a cadmium-plated nut with the IVD aluminum-coated bolt falls within nine percent of the cadmium baseline. The difference is within five percent for 11 of the 15 installation cycles as shown in Table 24.

The use of a supplemental, dry-film lubricant on the IVD aluminum-coated nut prior to application of MIL-T-5544 lessens the difference between IVD aluminum- and cadmium-finished hardware as shown in Table 25.

The best results were obtained using EM-6286. Differences were less than three percent for the first five installations and no more than 11 percent for the 15 cycles.

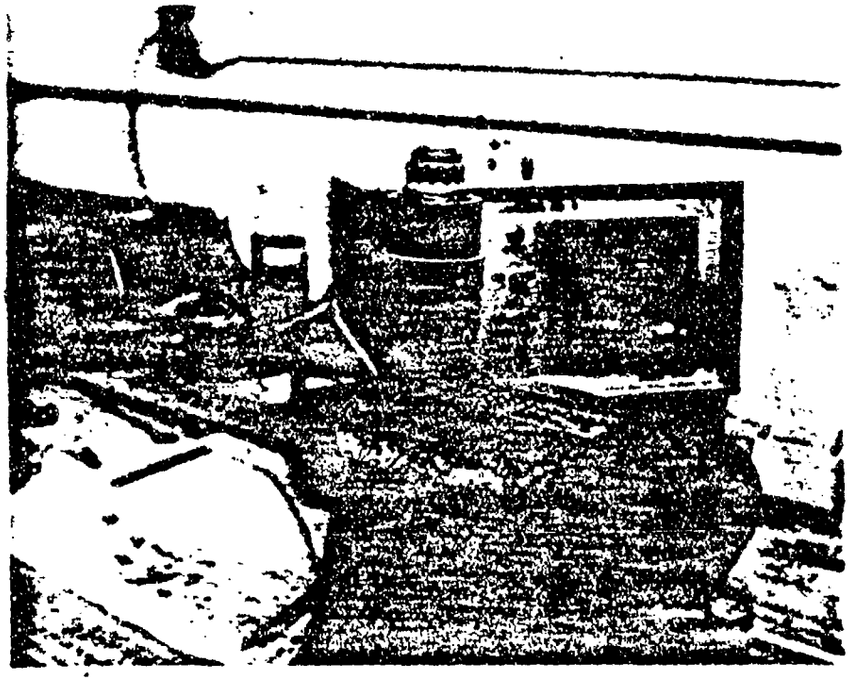


Figure 35. Use of Spacers to Compensate for Bolt Length

TABLE 24. AXIAL LOAD (POUNDS) GENERATED IN 3/4 INCH DIAMETER WHEEL TIE-BOLTS BY 2,100 INCH-POUNDS OF TORQUE.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut	Percent Change From Cd-Cd Baseline	IVD Al Bolt[a] and Cd Nut	Percent Change From Cd-Cd Baseline
1	39,543	33,800	-14.5	40,310	+1.9
2	39,310	35,270	-10.3	42,657	+8.5
3	39,083	33,837	-13.4	42,537	+8.8
4	40,023	35,240	-12.0	42,463	+6.1
5	40,326	35,537	-11.9	42,097	+4.4
6	42,627	36,423	-14.6	43,437	+1.9
7	42,200	36,460	-13.6	44,617	+5.7
8	43,053	36,280	-15.7	44,370	+3.1
9	42,960	37,080	-13.7	44,467	+3.5
10	43,740	36,847	-15.8	43,287	-1.0
11	44,937	37,200	-17.2	43,050	-4.0
12	44,660	37,903	-15.1	42,860	-4.2
13	44,323	37,373	-15.7	43,653	-1.5
14	43,887	36,880	-16.0	43,667	-0.5
15	43,123	38,137	-11.6	43,937	+1.9

a. Bolt and nut lubricated with C-801-S synthetic graphite before each installation.

TABLE 25. EFFECT ON AXIAL LOAD (POUNDS) GENERATED IN 3/4 INCH DIAMETER WHEEL TIE-BOLTS BY 2,100 INCH-POUNDS OF TORQUE WHEN SUPPLEMENTAL LUBRICANT IS APPLIED TO IVD ALUMINUM-COATED NUT.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut			Percent Change From Cd-Cd Baseline		
1	39,543	31,850[b]	36,840[c]	40,070[d]	-19.4[b]	-6.8[c]	+1.3[d]
2	39,310	37,630	37,080	39,160	-4.3	-5.7	-0.4
3	39,083	36,590	37,320	38,580	-6.4	-4.5	-1.3
4	40,023	37,040	39,910	38,940	-7.5	-0.3	-2.7
5	40,326	38,920	33,690	39,350	-3.5	-16.5	-2.4
6	42,627	36,900	35,950	39,850	-13.4	-15.6	-6.5
7	42,200	36,520	36,310	39,600	-13.5	-14.0	-6.2
8	43,053	36,310	35,510	38,300	-15.7	-17.5	-11.0
9	42,960	36,670	36,040	39,460	-14.6	-16.1	-8.1
10	43,740	36,820	36,700	39,640	-15.8	-16.1	-6.4
11	44,937	36,280	37,480	39,990	-19.3	-16.6	-11.0
12	44,660	35,870	37,010	39,980	-19.7	-17.1	-10.5
13	44,323	35,760	36,890	40,340	-19.3	-16.8	-9.0
14	43,881	34,900	38,670	39,540	-20.5	-11.9	-9.0
15	43,123	33,840	37,210	40,640	-21.5	-13.7	-5.6

a Bolt and nut lubricated with C-601-S synthetic graphite before each installation.
b Nut lubricated with Everlube 1346 dry-film lubricant before application of C-601-S.
c Nut lubricated with EM-6256 dry-film lubricant before application of C-601-S.
d Nut lubricated with EM-6286 dry-film lubricant before application of C-601-S.

The torque-tension comparison for the four bolt finish - nut finish - lubricant combinations described above are plotted in Figure 36.

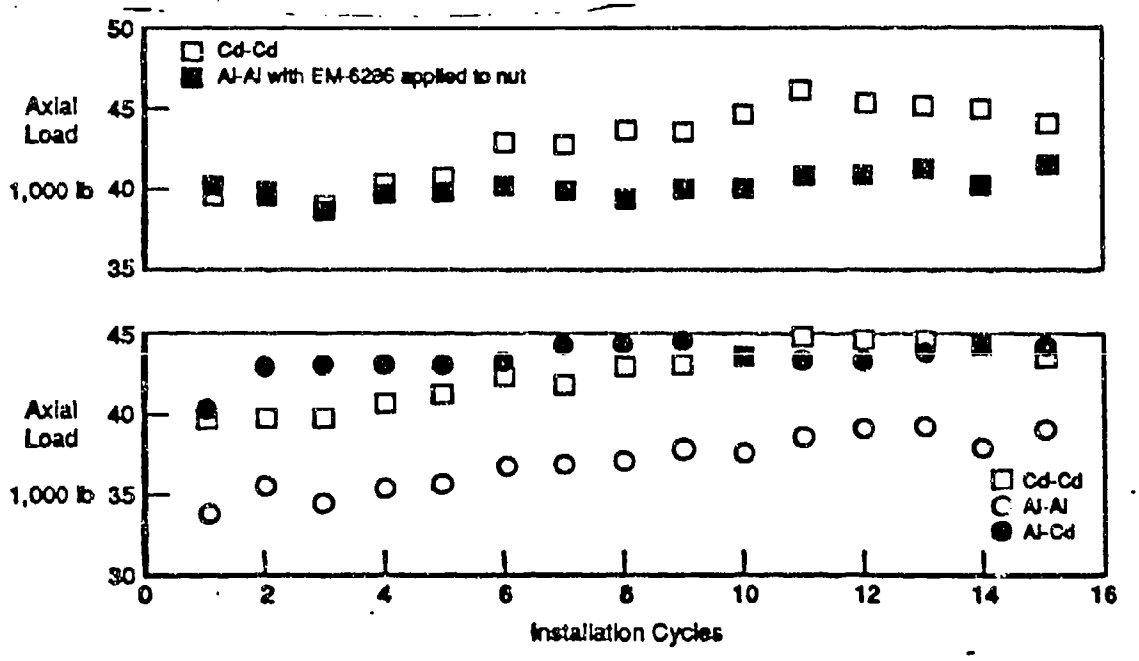


Figure 36. Axial Load Generated in 3/4 Inch Diameter Wheel Tie-Bolt by 2,100 Inch-Pounds of Torque.

b. For the 5/8-inch diameter hardware

The torque-tension comparisons generated for the 5/8-inch diameter tie-bolt show that the load generated by a torque of 1620 inch-pounds decreases for the IVD aluminum-coated hardware by 10-27 percent in relation to the cadmium-plated hardware (Table 26). The decrease generally drops below 20 percent after the second cycle.

TABLE 26. AXIAL LOAD (POUNDS) GENERATED IN 5/8 INCH DIAMETER WHEEL TIE-BOLTS BY 1,620 INCH-POUNDS OF TORQUE.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut	Percent Change From Cd-Cd Baseline	IVD Al Bolt[a] and Cd Nut	Percent Change From Cd-Cd Baseline
1	35,390	25,767	27.2	38,214	+8.0
2	33,693	26,213	22.2	34,983	+3.8
3	33,213	27,863	16.0	34,693	+4.5
4	34,093	28,730	15.7	35,017	+2.7
5	34,230	28,893	15.6	35,330	+3.2
6	34,057	29,847	12.4	35,033	+2.9
7	34,580	27,533	20.4	34,813	+0.7
8	34,477	28,170	18.3	35,477	+2.9
9	34,357	28,907	15.9	35,090	+2.1
10	34,080	28,903	15.2	35,333	+3.7
11	32,910	29,437	10.6	35,600	+8.2
12	32,790	28,977	11.6	35,767	+9.1
13	33,720	29,103	13.7	36,000	+6.7
14	32,790	29,327	10.6	35,943	+9.6
15	32,813	29,313	10.7	35,620	+8.6

a. Bolt and nut lubricated with C-601-S synthetic graphite before each installation.

The decrease transitioned to an increase in generated load when using a cadmium-plated nut with the IVD aluminum-coated bolt (Table 26) in relation to the cadmium baseline. Differences were less than 10 percent for all cycles and were within five percent for the second through the tenth cycle.

The use of a supplemental, dry-film lubricant on the IVD aluminum-coated nut prior to the application of MIL-T-5544 lessen the difference between IVD aluminum- and cadmium-finished hardware as shown in Table 27. The best results were obtained using EM-6256. Differences were less than five percent for the first four installation cycles and no more than 10 percent for the 15 cycles.

TABLE 27. EFFECT ON AXIAL LOAD (POUNDS) GENERATED IN 5/8 INCH DIAMETER WHEEL TIE-BOLTS BY 1,620 INCH-POUNDS OF TORQUE WHEN SUPPLEMENTAL LUBRICANT IS APPLIED TO IVD ALUMINUM-COATED NUT.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut			Percent Change From Cd-Cd Baseline		
1	35,390	33,475[b]	34,905[c]	34,615[d]	-5.4[b]	-1.4[c]	-2.2[d]
2	33,693	32,115	32,455	31,410	-4.7	-3.7	-6.8
3	33,213	32,265	31,825	31,675	-2.9	-4.2	-4.6
4	34,093	29,555	33,330	29,635	-13.3	-2.2	-13.1
5	34,230	30,475	32,060	29,025	-11.0	-6.3	-15.2
6	34,057	29,300	32,200	30,520	-14.0	-5.5	-10.4
7	34,580	29,455	30,980	30,810	-14.8	-10.4	-10.9
8	34,477	29,655	31,900	29,460	-14.0	-7.8	-14.6
9	34,357	29,200	31,530	29,940	-15.0	-8.2	-12.9
10	34,080	29,235	31,150	28,985	-14.2	-8.6	-15.0
11	32,910	29,575	30,695	28,770	-10.1	-6.7	-12.6
12	32,790	28,900	30,950	29,075	-11.9	-5.5	-11.3
13	33,720	28,980	31,000	29,170	-14.0	-8.1	-13.5
14	32,790	28,575	30,315	28,830	-12.9	-7.5	-12.1
15	32,813	29,975	30,655	28,390	-8.6	-6.6	-13.5

a Bolt and nut lubricated with C-601-S synthetic graphite before each installation.
b Nut lubricated with Everlube 1346 dry-film lubricant before application of C-601-S.
c Nut lubricated with EM-6256 dry-film lubricant before application of C-601-S.
d Nut lubricated with EM-6286 dry-film lubricant before application of C-601-S.

The torque-tension comparisons for the four bolt finish - nut finish - lubricant combinations described above are plotted in Figure 37.

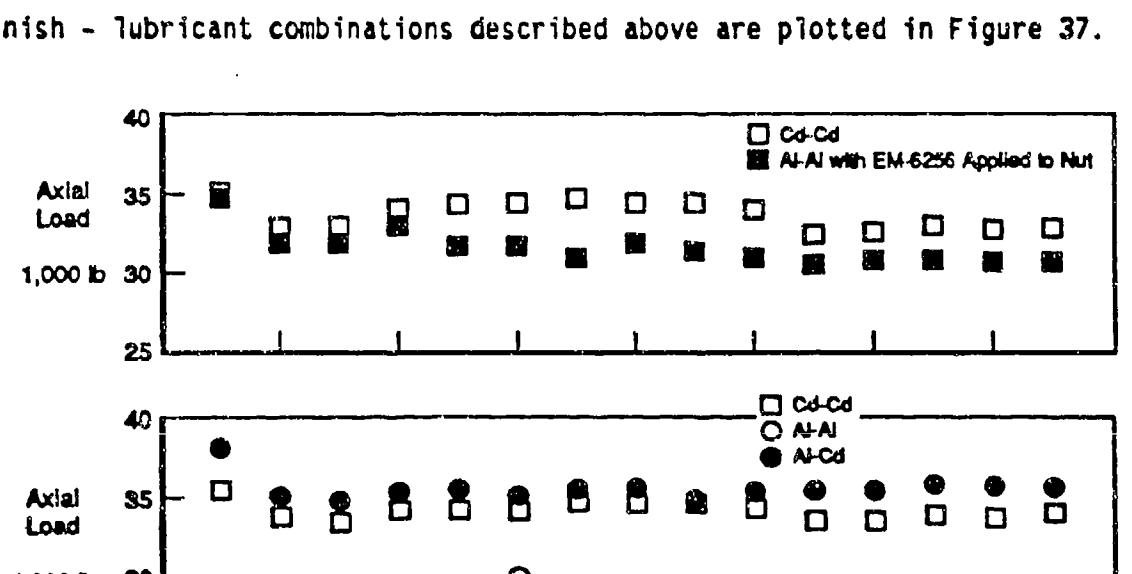


Figure 37. Axial Load Generated in 5/8 Inch Diameter Wheel Tie-Bolt by 1,620 Inch-Pounds of Torque.

c. For the 9/16-inch diameter hardware

The torque-tension comparisons generated for the 9/16-inch diameter tie-bolts show that the load generated by a torque of 1860 inch-pounds decreases for the IVD aluminum-coated hardware by 7-34 percent in relation to the vacuum cadmium-coated bolt and cadmium-plated nut (Table 28). The difference was less than 10 percent only in the first installation cycle.

TABLE 28. AXIAL LOAD (POUNDS) GENERATED IN 9/16 INCH DIAMETER WHEEL TIE-BOLTS BY 1,860 INCH-POUNDS OF TORQUE.

Inst'l Cycle	Vac Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut	Percent Change From Cd-Cd Baseline	IVD Al Bolt[a] and Cd Nut	Percent Change From Cd-Cd Baseline
1	37,283	34,820	-6.6	39,910	+7.0
2	37,803	29,530	-21.8	40,700	+7.7
3	39,000	27,190	-30.3	40,110	+2.8
4	39,803	30,450	-23.5	40,620	+2.1
5	41,230	31,340	-24.0	40,070	-2.8
6	42,317	29,740	-29.7	40,140	-5.1
7	42,567	29,500	-30.1	39,760	-6.6
8	42,173	29,430	-30.2	40,080	-5.0
9	42,270	29,540	-30.1	40,000	-5.4
10	42,407	29,800	-29.7	41,070	-3.2
11	43,887	29,580	-32.6	41,390	-5.7
12	44,570	29,170	-34.5	40,880	-8.3
13	43,820	29,200	-33.4	40,630	-7.3
14	44,467	29,360	-34.0	39,770	-10.6
15	44,353	29,550	-33.4	38,520	-13.2

a Bolt and nut lubricated with C-601-S synthetic graphite before each installation.

The decrease transitions to an increase in generated load for the first four cycles when using a cadmium-plated nut with the IVD aluminum-coated bolt (Table 28) in relation to the cadmium baseline. Differences were less than 10 percent for the first 13 cycles.

The torque-tension comparisons for the bolt finish - nut finish - lubricant combinations described above are plotted in Figure 38.

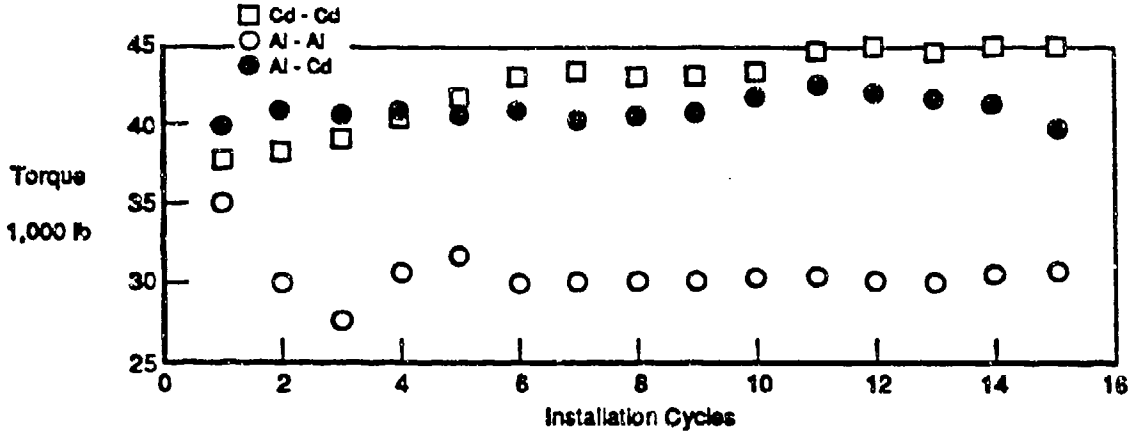


Figure 38. Axial Load Generated in 9/16 Inch Diameter Wheel Tie-Bolt by 1,860 Inch-Pounds of Torque.

d. For the 5/16-inch diameter hardware

The torque-tension comparisons generated for the 5/16-inch diameter tie-bolts show that the load generated by a torque of 250 inch-pounds is essentially the same for the IVD aluminum- and cadmium-finished hardware (Table 29).

TABLE 29. AXIAL LOAD (POUNDS) GENERATED IN 5/16 INCH DIAMETER WHEEL TIE-BOLTS BY 250 INCH-POUNDS OF TORQUE.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut	Percent Change From Cd-Cd Baseline	IVD Al Bolt[a] and Cd Nut	Percent Change From Cd-Cd Baseline
1	8,378	8,112	−3.2	9,267	+10.6
2	7,897	7,995	+1.2	9,086	+15.1
3	8,177	8,585	+5.0	8,524	+4.2
4	8,229	8,897	+8.1	8,652	+5.1
5	8,294	8,222	−0.9	8,742	+5.4
6	8,492	8,552	+0.7	9,011	+6.1
7	8,543	8,750	+2.4	9,004	+5.4
8	8,773	8,840	+0.8	9,083	+3.6
9	8,571	8,823	+2.9	9,292	+8.4
10	8,885	8,748	−1.5	9,404	+5.8
11	8,720	8,729	+0.1	9,328	+7.0
12	8,827	8,797	−0.3	9,614	+8.9
13	8,798	8,923	+1.4	9,691	+10.3
14	8,910	8,748	+1.8	9,809	+10.1
15	8,757	8,813	+0.6	9,762	+11.5

a Bolt and nut lubricated with C-601-S synthetic graphite before each installation.

The use of a cadmium-plated nut with the IVD aluminum-coated bolt increased the load generated in the IVD aluminum-coated bolt in relation to the cadmium baseline (Table 29). The increase is generally within 11 percent for 14 of the 15 installation cycles.

The use of a supplemental, dry film lubricant on the IVD aluminum-coated nut prior to application of MIL-T-5544 also increased the load generated in the IVD aluminum-coated bolt in relation to cadmium baseline (Table 30). The differences were generally less than 10 percent. The best results were obtained using Everlube 1346. Differences were less than seven percent for all 15 cycles.

TABLE 30. EFFECT ON AXIAL LOAD (POUNDS) GENERATED IN 5/16 INCH DIAMETER WHEEL TIE-BOLTS BY 250 INCH-POUNDS OF TORQUE WHEN SUPPLEMENTAL LUBRICANT IS APPLIED TO IVD ALUMINUM-COATED NUT.

Inst'l Cycle	Cd Bolt[a] and Cd Nut	IVD Al Bolt[a] and IVD Al Nut			Percent Change From Cd-Cd Baseline		
1	8,378	8,192[b]	9,518[c]	9,332[d]	-2.2[b]	+13.6[c]	+11.4[d]
2	7,897	8,373	8,806	8,542	+6.0	+11.5	+8.2
3	8,177	8,540	8,617	8,440	+4.4	+5.4	+3.2
4	8,229	8,598	8,772	8,851	+4.5	+6.6	+7.6
5	8,294	8,429	8,461	8,774	+1.6	+2.0	+5.6
6	8,492	8,624	8,556	8,974	+1.6	+0.8	+5.7
7	8,543	9,102	8,977	9,199	+6.5	+5.1	+7.7
8	8,773	8,966	9,046	9,202	+2.2	+3.1	+4.9
9	8,571	8,990	8,985	9,328	+4.9	+4.8	+8.8
10	8,885	8,956	9,178	9,518	+0.8	+3.3	+7.1
11	8,720	9,250	9,128	9,538	+6.1	+4.7	+9.4
12	8,827	9,118	9,180	9,634	+3.3	+4.0	+9.1
13	8,798	9,180	9,299	9,509	+4.3	+5.7	+7.3
14	8,910	9,462	9,374	9,734	+6.2	+5.2	+9.2
15	8,757	9,120	9,087	9,878	+4.1	+3.8	+12.8

a Bolt and nut lubricated with C-601-S synthetic graphite before each installation.
b Nut lubricated with Everlube 1346 dry-film lubricant before application of C-601-S.
c Nut lubricated with EM-6256 dry-film lubricant before application of C-601-S.
d Nut lubricated with EM-6296 dry-film lubricant before application of C-601-S.

The torque-tension comparisons for the four bolt finish - nut finish - lubricant combinations described above are plotted in Figure 39.

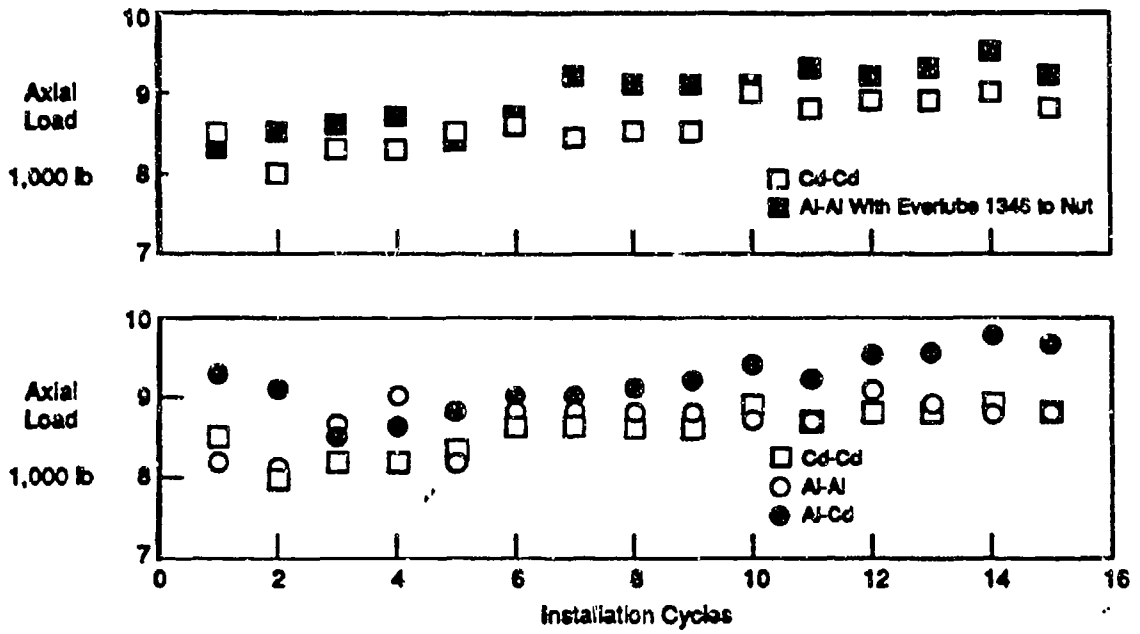


Figure 39. Axial Load Generated in 5/16 Inch Diameter Wheel Tie-Bolt by 250 Inch-Pounds of Torque.

3. Engine Bolt Torque-Tension Data

MCAIR coordinated a test program with the OC-ALC (References 15, 16, 17) in which torque-tension comparisons were established for the following TF30 engine hardware:

o The OC-ALC/MMPRA (D. L. Evans) supplied MS9209-13 diffused nickel-cadmium plated bolts and Pratt & Whitney (P&W) 564706 cadmium-plated nuts that are used on the TF30 assembly. The 1/4-inch diameter hardware is lubricated with MIL-L-23699 engine oil before installation.

o MCAIR obtained MS9210-25 diffused nickel-cadmium plated bolts and P&W 767709 cadmium-plated nuts to repeat a P&W test (Reference 10). The P&W test showed significantly lower loads developed with the IVD

aluminum-coated hardware in relation to diffused nickel-cadmium plated bolt and cadmium-plated nut hardware combinations at similar torque values. P&W tested the 5/16-inch diameter hardware lubricated with MIL-L-23699 engine oil.

MCAIR removed the diffused nickel-cadmium and cadmium platings from half of the hardware. These nuts and bolts were then coated with an IVD aluminum, Class 3, Type II coating per MIL-C-83488 to meet the design requirement for thickness which is 0.0003-0.0005 inches. Descriptions of the bolt and nut are shown in Tables 31 and 32, respectively.

TABLE 31. DESCRIPTION OF TF30 ENGINE BOLTS.

Bolt Description	Bolt Designation	Thread Size and Description	Bolt Length		Corrosion Preventive Finish	
			Grip (In.)	Total (In.)	Cadmium	IVD Aluminum
Machine-Steel, AMS 6304, Diffused Nickel-Cadmium Plated, Double Hexagon Extended Washer Head, 0.3125-24 UNJF-3A	MS9210-25	0.3125-24 UNJF-3A	0.940 –	1.875	Diffused Nickel-Cadmium Plate Per AMS 2416	Class 3, Type II, Per MIL-C-83488
Machine-Steel, AMS 6304, Diffused Nickel-Cadmium Plated, Double Hexagon Extended Washer Head, 0.250-28 UNJF-3A	MS9209-13	0.2500-28 UNJF-3A	0.128 – 0.188	0.938	Diffused Nickel-Cadmium Plate Per AMS 2416	Class 3, Type II, Per MIL-C-83488

TABLE 32. DESCRIPTION OF TF30 ENGINE NUTS.

Nut Description	Nut Designation	Thread Size and Description	Nut Height	Corrosion Preventive Finish	
				Cadmium	IVD Aluminum
Flexloc, Tension, Double Hexagon, Flanged, Self-Locking, Alloy Steel, 180 ksi, 450°F Lightweight	42FLW-524 (SPS Tech)	0.3125-24 UNJF-3B	0.363	Plate Per QQ-P-416, Type I, Class 3	Class 3, Type II, Per MIL-C-83488
Double Hexagon, Self-Locking, Alloy Steel	564706 (P&W)	0.2500-28 UNJF-3B	0.363	Plate Per QQ-P-416, Type II, Class 2	Class 3, Type II, Per MIL-C-83488

The torque-tension data was generated by holding the bolt head fixed and rotating the nut. The test set-up was the same as that described for Figure 32 except a GSE, Inc. Model FT-250 Fastener Force Transducer was used for the 1/4-inch diameter hardware and a Model FT-312 was used for the 5/16-inch diameter hardware. The same transducers were used, and their calibration was verified to be correct, throughout the evaluation.

a. For TF-30 engine hardware

MCAIR generated torque-tension data for six-sets of MS9209-13 bolts and P&W 564706 nuts with the following bolt finish - nut finish - lubricant combinations:

- Three-sets had the bolts and nuts coated with IVD aluminum and were lubricated with MIL-L-23699 engine oil.

- Three-sets had the bolts plated with diffused nickel-cadmium and the nuts plated with cadmium and were lubricated with MIL-L-23699 engine oil.

A thin film of engine oil lubricant was brush applied to the threaded areas of the nuts and bolts. The lubricant was removed and reapplied between each installation. The data generated for each set of fasteners is located in Appendix C and consists of the same information outlined for Figure 33 except:

- Running torque (loading cycle), breakaway torque, and running torque (removal cycle) - were measured on the first and fifth loading/removal cycles.

- Torque-tension relationship - this relationship was established by recording the tensile loads generated by 65 and 85 inch-pounds of torque which is the normal installation range. The tensile load generated

by 85 inch-pounds of torque was measured for five cycles. The tensile load generated by 65 inch-pounds of torque was recorded for the first and fifth installation cycles.

The torque-tension comparisons generated during this test (Table 33) show that the lubricated IVD aluminum-coated hardware was actually more highly loaded by both 65 and 85 inch-pounds of torque during the first two installation cycles than was the diffused nickel-cadmium plated bolt - cadmium plated nut combination. The torque-tension relationship transitioned during the second, third, and fourth cycles from being slightly more lubricious with IVD aluminum plus oil to being slightly more lubricious with diffused nickel-cadmium and cadmium plus oil. The load generated in the IVD aluminum-coated hardware ranges from 41 percent higher to 13 percent lower using the load generated in diffused nickel-cadmium plated hardware as the baseline. The items to be considered include:

o The higher load generated by 85 inch-pounds of torque for the IVD aluminum-coated condition during the first installation cycle does not "overload" the fastener. The average generated load of 2493 pounds is only 33 percent of the ultimate strength of the bolt.

o The total "scatter" between the highest and lowest IVD aluminum loads and the highest and lowest diffused nickel-cadmium loads is only 14 percent at the high end and 6 percent at the low end. In other words, the highest loaded IVD aluminum cycle (first) produces a 14 percent improvement over the highest loaded diffused nickel-cadmium cycle (fourth) while the lowest IVD aluminum cycle (fifth) produces a 6 percent improvement over the lowest loaded diffused nickel-cadmium cycle (first). See Figure 40.

b. For repeat of test

MCAIR generated torque-tension data for 14-sets of MS9210-25 bolts and SPS 42FLW-524 nuts with the following bolt finish - nut finish - lubricant combinations to repeat the P&W test (Reference 10):

TABLE 33. COMPARISON OF LOADS GENERATED FOR IVD ALUMINUM-COATED AND DIFFUSED NICKEL-CADMIUM PLATED HARDWARE LUBRICATED WITH OIL: MS9209-13 BOLTS AND P&W 564706 NUTS.

Installation Cycle	Axial Load (lb) Generated by 85 (in.-lb) of Torque		Percent Change From Cadmium[a] Baseline
	Cadmium[a]	IVD Aluminum[b]	
1	1109	1785	+61
5	1560	1476	–5
	Axial Load (lb) Generated by 85 (in.-lb) of Torque		
1	1767	2493	+41
2	1899	2090	+10
3	2017	1919	–5
4	2178	1896	–13
5	2142	1879	–12

a Cadmium indicates a diffused nickel-cadmium plated bolt and a cadmium plated nut.

b IVD aluminum indicates an IVD aluminum coated bolt and nut.

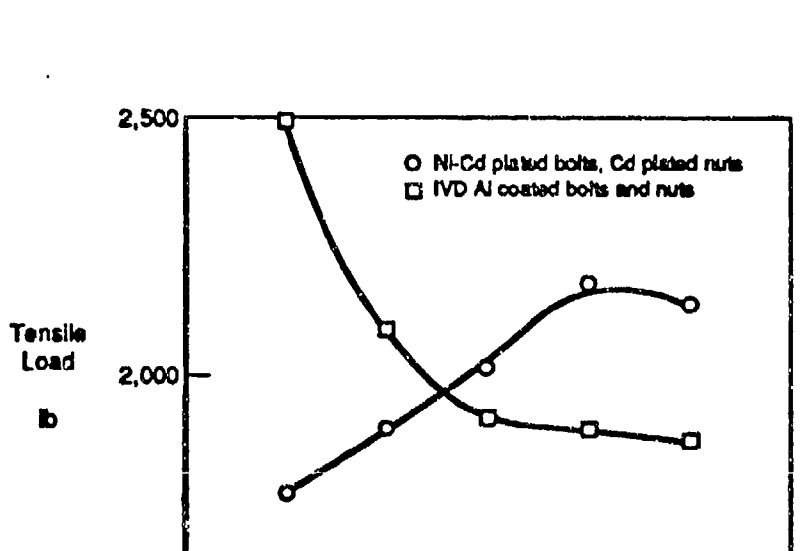


Figure 40. Tensile Load Generated by 85 Inch-Pounds of Torque: MS9209-13 Bolts – P&W 564706 Nuts.

- Six-sets had the bolts and nuts finished with IVD aluminum. Three sets were lubricated with MIL-L-23699 engine oil. The other three-sets were not lubricated.

- Six-sets had the bolts finished with diffused nickel-cadmium and the nuts with cadmium. Three sets were lubricated with MIL-L-23699 engine oil. The other three-sets were not lubricated.

- Two-sets had the bolts finished with IVD aluminum and the nuts finished with cadmium. One set was lubricated with MIL-L-23699 engine oil. The other set was not lubricated.

For the lubricated hardware, a thin film of engine oil was brush applied to the threaded areas of the nuts and bolts. The lubricant was removed and reapplied between each installation. The data generated for each set of fasteners is located in Appendix C and consists of the same information outlined for Figure 33 except:

- Running torque (loading cycle), breakaway torque, and running torque (removal cycle) - were recorded on the first and fifth loading/removal cycles (first only for non-lubricated hardware).

- Torque-tension relationship - The tensile load generated by 100, 200, and 300 inch-pounds of torque was measured for five installation cycles (one cycle only for non-lubricated hardware) which was a repeat of the P&W test procedure (Reference 10).

The torque-tension comparisons (Table 34) generated during this test show a decrease in axial load generated by the lubricated IVD aluminum-coated hardware in relation to the lubricated diffused nickel-cadmium baseline. The decrease, however, is in the area of 20 percent and may fall into an acceptable installation range. In contrast, the P&W data showed decreases in the amount of load generated by aluminum-coated hardware in the area of 70 percent.

TABLE 34. COMPARISON OF AXIAL LOADS GENERATED FOR IVD ALUMINUM COATED AND DIFFUSED NICKEL-CADMIUM – CADMIUM PLATED HARDWARE LUBRICATED WITH OIL: MS9210-25 BOLTS AND SPS 42FLW-524 NUTS.

Installation Cycle	Axial Load (lb) Generated by 100 (in.-lb) of Torque		Percent Decrease From Cadmium[a] Baseline
	Cadmium[a]	IVD Aluminum[b]	
1	2452	2013	17.9
5	2017	1571	22.1
	Axial Load (lb) Generated by 200 (in.-lb) of Torque		
	Cadmium[a]	IVD Aluminum[b]	
1	5465	4506	17.5
5	4039	3370	16.6
	Axial Load (lb) Generated by 300 (in.-lb) of Torque		
	Cadmium[a]	IVD Aluminum[b]	
1	8269	6366	23.0
5	6300	4795	25.0

a Cadmium indicates a diffused nickel-cadmium plated bolt and a cadmium plated nut.

b IVD aluminum indicates an IVD aluminum coated bolt and nut.

Figure 41 shows the original data generated by P&W plotted against the newly generated MCAIR data. The P&W data was unique in that it is the only entry in the MCAIR test data library that shows such wide differences in torque-tension characteristics between IVD aluminum and cadmium when using lubrication.

The value of lubricating IVD aluminum-coated hardware is exemplified by comparing the decrease in generated loads when comparing non-lubricated IVD aluminum to non-lubricated diffused nickel-cadmium. In this situation, there is a decrease in generated load of 50 percent and more (Table 35) with IVD aluminum.

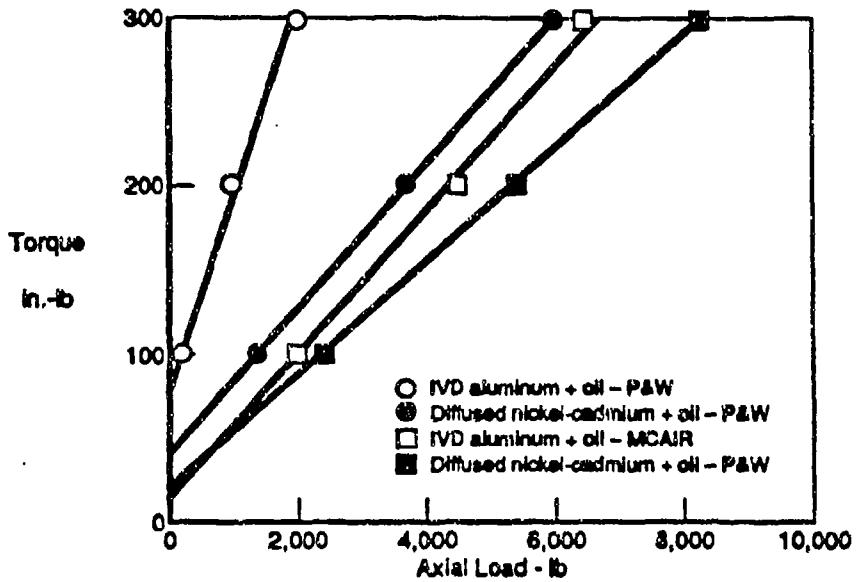


Figure 41. Comparison of Torque vs Axial Load for Data Generated by P&W and by MCAIR for Diffused Nickel-Cadmium and IVD Aluminum-Finished Hardware.

TABLE 35. COMPARISON OF AXIAL LOADS GENERATED FOR VARIOUS BOLT FINISH – NUT FINISH COMBINATIONS THAT ARE NOT LUBRICATED WITH OIL: MS9210-25 BOLTS AND SPS 42FLW-524 NUTS.

Torque (In.-lb)	Axial Load (lb) Generated by 100 In.-lb of Torque			Percent Decrease From Cadmium[a] Baseline	
	Cd-Cd[a]	IVD Al-IVD Al[b]	IVD Al-Cd[c]	IVD Al-IVD Al[b]	IVD Al-Cd[c]
100	2,919	1,107	2,876	62.1	1.5
200	6,353	2,005	5,529	68.4	14.9
300	9,091	4,719	7,886	48.1	13.2

a Cd-Cd indicates a diffused nickel-cadmium plated bolt and a cadmium plated nut.
b IVD Al-IVD Al indicates an IVD aluminum coated bolt and nut.
c IVD Al-Cd indicates an IVD aluminum-coated bolt and a cadmium-plated nut.

MCAIR projects that the combination of IVD aluminum-coated bolts and cadmium-plated nuts is a probability at most of the ALCs for reasons stated earlier in this section. The torque-tension data for this combination is shown in Table 36. It shows a decrease in the axial load generated in the IVD aluminum-coated bolt in the first cycle. This transitions to a substantial increase in axial load generated in the fifth cycle.

TABLE 36. COMPARISON OF AXIAL LOADS GENERATED FOR IVD ALUMINUM-COATED BOLT – CADMIUM-PLATED NUT AND DIFFUSED NICKEL-CADMIUM-PLATED BOLT – CADMIUM-PLATED NUT WHEN LUBRICATED WITH OIL: MS9210-25 BOLTS AND SPS 42FLW-524 NUTS.

Installation[a] Cycle	Axial Load (lb) Generated by 100 In.-lb of Torque		Percent Change From Cd-Cd Baseline
	Cd-Cd[b]	IVD Al-Cd[c]	
1	2,452	2,624	+7.0
5	2,017	3,091	+53.2
	by 200 In.-lb of Torque		
	Cd-Cd	IVD Al-Cd	
1	5,465	5,145	–5.9
5	4,039	6,080	+50.5
	by 300 In.-lb of Torque		
	Cd-Cd	IVD Al-Cd	
1	8,269	8,785	+6.2
5	8,638	8,933	+3.4
3	7,666	9,678	+26.2
4	6,987	9,189	+31.5
5	6,300	8,592	+36.0

a All bolts and nuts lubricated with MIL-L-23699 engine oil
b Cd-Cd indicates a diffused nickel-cadmium plated bolt and cadmium-plated nut.
c IVD Al-Cd indicates an IVD aluminum-coated bolt and cadmium-plated nut.

D. SUPPORTING TORQUE/TENSION DATA

The following torque-tension data was compiled during Phase I of this program (Reference 1).

MCAIR stated in Reference 1 that aluminum has a higher coefficient of friction than cadmium. Therefore, a higher torque is required to install aluminum-coated fasteners to a given tension preload than if the fastener was

cadmium plated. It was also reported that the use of a lubricant on the aluminum-coated fastener and/or nut, however, eliminates or greatly reduces torque-tension differences. This section of supporting data compares torque-tension values for IVD aluminum, cadmium, and diffused nickel-cadmium finished fasteners with and without the use of lubricants.

SPS Technologies (Reference 18) generated torque-tension data for IVD aluminum-coated and cadmium-plated alloy steel hardware; H-11 EBW22-4-22 bolts and F22 locknuts. When both the bolt and nut were coated with IVD aluminum, approximately 60 percent more torque was needed to produce a 2000 pound tension load then when both were cadmium-plated. Using a cadmium-plated nut with the IVD aluminum-coated bolt reduced the difference to approximately 15 percent. When the IVD-coated nuts and bolts were lubricated with cetyl alcohol, the torque for a given induced tension load was actually 70 percent less than if the nut and bolt were cadmium-plated. In this test, therefore, the effect of the lower lubricity of the IVD aluminum coating was more than offset by the addition of a lubricant.

MCAIR compiled data from two series of torque-tension tests (Reference 19) conducted during formal qualification of IVD aluminum as an acceptable alternative to cadmium. In the first series of tests, the initial torque required to develop a 1200-pound tension load in 3/16-inch diameter nonlubricated, IVD aluminum-coated or cadmium-plated bolts was measured for various nut configurations. The relative torque differences, based on an average of 8 tests for each condition, are as follows:

- An 8 percent higher torque was required using IVD aluminum versus cadmium when the torque was applied to cadmium-plated, nonlocking, nonlubricated nuts.

- An 8 percent higher torque was required using IVD aluminum versus cadmium when the torque was applied to cadmium-plated, dry-film-lubricated, self-locking nuts.

- The same torque was required using IVD aluminum- and cadmium-finished bolts when the torque was applied to the bolts with cadmium-plated, dry-film-lubricated, self-locking nuts.

- A 36 percent higher torque was required using IVD aluminum versus cadmium when the torque was applied to the bolts with cadmium-plated, dry-film-lubricated, self-locking gang channel nuts.

In the second series of tests, the initial torque required to induce a specific tension load in 3/16-inch diameter, IVD aluminum-coated or cadmium-plated bolts was measured. Some of the bolts were lubricated and the torque was applied to cadmium-plated, dry-film-lubricated, self-locking nuts. The test results are as follow:

- A 10 percent higher torque was required using IVD aluminum versus cadmium to attain a 560-pound load in a nonlubricated bolt.

- An 8 percent higher torque was required using IVD aluminum versus cadmium to attain a 560-pound load in a lubricated bolt.

- The torques required using IVD aluminum and cadmium finishes were approximately the same to attain a 2000-pound load in a lubricated bolt.

Boeing conducted torque-tension tests comparing IVD aluminum and diffused nickel-cadmium on nonlubricated H-11 steel bolts (Reference 11). The bolts were loaded to 50 percent of their yield strength. The torque-tension curves produced using the IVD aluminum finish were nearly identical to those produced using diffused nickel-cadmium.

The Hi-Shear Company also evaluated torque-tension using IVD aluminum and diffused nickel-cadmium on lubricated H-11 pin and collar type fasteners (Reference 12). They reported that torque-tension was essentially unaffected by any differences in the two finishes.

In contrast however, P&W reported that a considerably higher torque was required with IVD aluminum in comparison to diffused nickel-cadmium (Reference 10). Axial load versus applied torque for 30 bolts (MS9210-21) finished with IVD aluminum and diffused nickel-cadmium was evaluated. The effect on engine oil on the bolts was also measured since it was common practice to dip the bolt in oil before assembly. In all cases, the IVD aluminum-finished bolts required a higher torque to produce the same axial load than did the diffused nickel-cadmium-finished bolts. For example, the diffused nickel-cadmium finished bolt was torqued to 70 inch-pounds to produce a load of 1000 pounds while the aluminum-finished bolt required 168 inch-pounds. MCAIR repeated this test earlier in this section and reported torque-tension differences of about 20 percent between IVD aluminum and diffused nickel-cadmium.

A review of production operations involving the use of IVD aluminum as a replacement for cadmium on fasteners verifies the relative ease that such a changeover can be accomplished for most applications. Some of these operations have been ongoing for the past 14 years. For the most part, they have been accomplished with no more than the use of a lubricant and without significant changes to installation procedures or tools.

E. DISCUSSION

MCAIR generated a significant fastener installation databank by recording torque-tension and other installation characteristics for 174 sets of hardware with various bolt finish - nut finish - lubricant combinations. This activity was directed at wheel tie-bolts and threaded engine hardware. These applications were identified as being areas of concern when replacing cadmium processing with IVD aluminum at the ALCs.

Torque-tension data was generated to:

- Establish a baseline for the cadmium finishes and lubricants now in use at the ALCs.

o Directly compare IVD aluminum-coated bolts and nuts to the cadmium-plated baseline.

o Directly compare the combination of IVD aluminum-coated bolts and cadmium-plated nuts to the cadmium-plated baseline.

o Establish procedures/lubricants which will lessen the basic difference between IVD aluminum and cadmium without impacting existing ALC procedures.

1. Wheel-Tie Bolts

MCAIR conducted evaluations on generic wheel tie-bolts first. This study established a baseline for cadmium-plated hardware with synthetic graphite - petrolatum lubrication per MIL-T-5544 which is now in use at the ALCs. The study also indicated that the use of MIL-T-5544 and MIL-T-83483 lubrications produced the best results of the various lubricants tested for cadmium-plated hardware. MIL-T-83483 is allowed as an optional lubricant for some wheel tie-bolts but its use is minimal in comparison to MIL-T-5544 at the ALCs. Therefore, the baseline for the actual cadmium-plated wheel tie-bolts was also established with MIL-T-5544.

Direct comparisons between IVD aluminum- and cadmium-finished wheel tie-bolts lubricated with MIL-T-5544 established that more torque is required to generate a specific load in the IVD aluminum-coated hardware. The difference is generally most pronounced for the first installation or two and is in the general area of 20 percent. This difference lessens with installations as the IVD aluminum coating is "broken in". There was no indication of galling or seizing during the 15-cycle installation. In fact, the IVD aluminum-coated hardware trended to be more lubricious with usage. A "break-in" installation cycle or two would be advantageous providing the hardware is lubricated for each installation.

The combination of IVD aluminum-coated bolts and cadmium-plated nuts compared very favorably in all cases with the cadmium-finished baseline for both the generic evaluation and testing of actual wheel tie-bolt hardware.

This combination is the most probable at the ALCs. Nuts are usually scrapped during a maintenance overhaul for both economical and functional reasons. New nuts that are then used with the refurbished bolts are vendor supplied with a cadmium finish. There are no current plans to change the finish on vendor-supplied hardware.

The use of a supplemental dry-film lubricant applied to the IVD aluminum-coated nut prior to application of MIL-T-5544 synthetic graphite lessens the difference between aluminum-coated hardware and the cadmium-finished baseline. The effect of the dry-film supplemental lubricant is the most pronounced during the first several installations before it begins to wear. Once worn, this combination basically tracks the results of IVD aluminum coating without supplemental dry-film. The benefit during the first several installation cycles is significant in that the most difference between IVD aluminum and cadmium otherwise occurs in the first several cycles. The use of a supplemental lubricant on IVD aluminum-coated nuts should have little impact on the ALCs as lubricated nuts would be vendor supplied. A finish change to IVD for vendor-supplied hardware would include a requirement for the dry film lubricant.

2. Engine Bolts

The torque-tension baseline for the threaded engine hardware was established for the actual ALC practice; namely, diffused nickel-cadmium plated bolts and cadmium-plated nuts lubricated with MIL-L-23699 engine oil.

Direct comparisons between IVD aluminum-coated and the cadmium baseline produced mixed results. The IVD-coated hardware was more highly loaded during the first few installation cycles for the MS9209-13 bolts and P&W 564706 nuts. The cadmium-finished hardware was more highly loaded for the

MS9210-25 bolts and SPS 42FLW-524 nuts. Torque-tension characteristics for both aluminum and cadmium varied significantly during a five-cycle evaluation. There was more consistency with IVD aluminum as generated loads dropped for subsequent installations during both tests. Generated loads for cadmium increase in one test and decrease in the other. There was little difference between aluminum and cadmium when their perspective highs and lows were compared.

The use of a cadmium-plated nut with the IVD aluminum-coated bolt resulted in significantly higher loads generated in the IVD aluminum - cadmium combinations when comparing relative installation cycles. This difference once again was greatly reduced when comparing perspective highest loads.

MCAIR suggests that the only significant concern may be with the use of a combination consisting of an IVD aluminum-coated bolt and nut with no lubrication. Even without lubrication, the difference is greatly alleviated with the use of a cadmium-plated nut.

F. CONCLUSION

MCAIR concludes that both wheel tie-bolts and engine bolts can be refurbished by the ALCs with IVD aluminum in place of both cadmium and diffused nickel-cadmium without torque-tension concerns when used with either cadmium-plated or IVD aluminum-coated nuts and existing ALC lubricants.

MCAIR suggests, however, that in the event of concern, the ALCs may want to consider the use of a supplemental dry-film lubricant plus the standard MIL-T-5544 lubricant on the nuts when using IVD aluminum-coated wheel tie-bolts and nuts.

SECTION V

EROSION RESISTANCE CHARACTERISTICS

A. PROBLEM

IVD aluminum is relatively soft, as is cadmium. Neither is well suited for applications requiring a high degree of erosion resistance. Diffused nickel-cadmium is more erosion resistant than cadmium by itself and is commonly used by the ALCs on engine details. IVD aluminum can easily be applied thicker than what is normal for nickel-cadmium, and this advantage may result in comparable erosion resistance or even improved erosion/corrosion resistance. Thicker IVD aluminum coatings may not always be possible, however, because of tolerance limitations. Therefore, an improvement in erosion resistance is desired when there is a requirement to use thinner IVD aluminum coatings.

B. SOLUTION/APPROACH

Preliminary erosion resistance testing of an IVD aluminum basecoat enhanced by an erosion resistant topcoat was encouraging. It is proposed that this work be continued. Work by Chromalloy Compressor Technologies, for example, demonstrated the erosion-resistant characteristics of an IVD aluminum basecoat with their specially formulated conversion topcoat (Reference 20). Although the comparison was not with a cadmium process, it does indicate the potential for such combination coatings.

Another area that may be investigated is the erosion resistance of various aluminum alloys applied by the IVD process. An aluminum alloy different than the soft, basically pure, 1100 aluminum alloy that is normally used may well provide improved erosion resistance.

C. DATA

MCAIR initially generated comparative erosion resistance data between IVD aluminum coating and diffused nickel-cadmium. After establishing baselines with these two protective finishes, MCAIR evaluated the effect of different sealcoats/topcoats, additional aluminum alloys as the IVD evaporant, as well as ceramic-metallic paint-type coatings in relation to the baseline values.

The various finishes were applied to 4-inch by 6-inch alloy steel panels. All of the comparative data was generated by glass bead peening. BT-10 glass beads were used at peen pressures of 40 and/or 60 psi. The peener nozzle was held six-inches above the finished panel in such a manner as to provide a 90-degree-impingement angle. The erosion resistance test stand is shown in Figure 42.

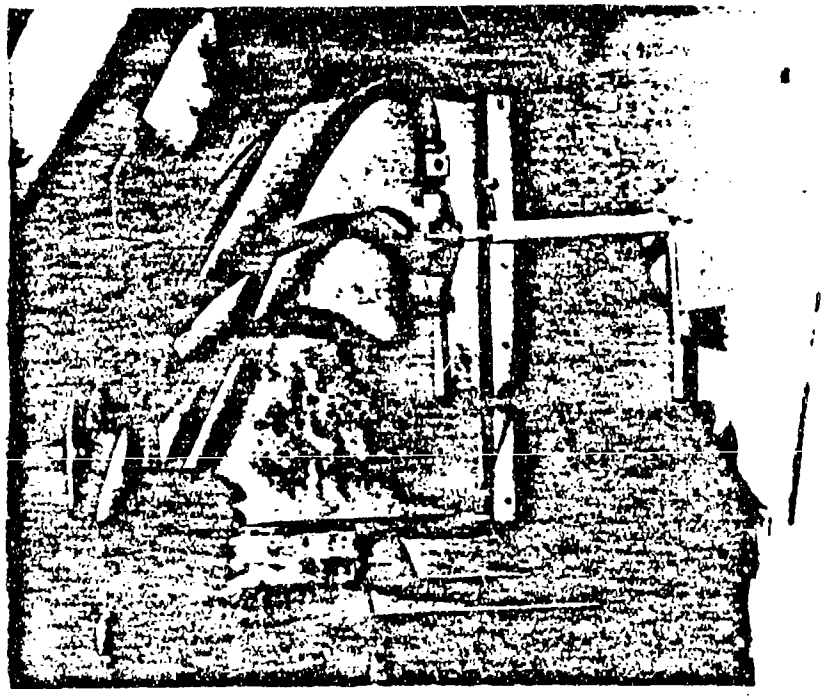


Figure 42. Erosion Resistance Test Stand.

Erosion rates are based on the first indication of penetration through the protective finish to the substrate. It is noteworthy to mention that the failure mode for IVD aluminum coatings generally consisted only of a small void(s) within the erosion pattern area in the coating. The remaining aluminum coating in the pattern area was generally 0.0001-0.0003 inch which would still offer corrosion- and erosion-resistance protection. Diffused nickel-cadmium, on the other hand, eroded more evenly with virtually no protective finish remaining in the erosion-pattern area.

Erosion-resistance baselines are shown in Table 37 for IVD aluminum coating using 1100 aluminum and for diffused nickel-cadmium. The 1100 alloy aluminum wire is the standard evaporant used with the IVD process and is 99 percent pure aluminum at a minimum. The baseline data indicates that the erosion rate for 1100 alloy IVD aluminum coating is 3.5-4.0 times faster than that for diffused nickel-cadmium.

TABLE 37. EROSION RESISTANCE BASELINE: IVD ALUMINUM AND DIFFUSED NICKEL-CADMIUM.

Protective Finish	Erosion Rate (mils per second)	
	40 psi	60 psi
IVD Aluminum	0.0048	0.0087
Diffused Nickel-Cadmium	0.0012	0.0025

These differences can be readily offset for most applications involving refurbished engine details with a thicker IVD aluminum coating that can be easily applied without functional degradation.

MCAIR, however, did evaluate the effect of various sealcoats/topcoats and aluminum-alloy evaporants for those applications where coating thickness may

be a factor. The best results were obtained with an aluminum-alloy evaporant that contained 12-percent silicon. This finish, which can be deposited with standard IVD aluminum coating equipment, showed an improvement of 40-percent over the standard 1100 aluminum alloy when peened at 40 PSI (Table 38).

TABLE 38. EROSION RESISTANCE COMPARISON OF ALUMINUM ALLOY EVAPORANTS.

Aluminum Alloy Evaporant	Erosion Rate (mils per second)	
	40 psi	60 psi
1100 Al [a]	0.0048	0.0087
Al-6% Si [b]	0.0046	0.0071
Al-12% Si [c]	0.0029	0.0072

a Alloy contains approximately 99% aluminum
b Alloy contains approximately 94% aluminum – 6% silicon
c Alloy contains approximately 88% aluminum – 12% silicon

Approximately 54 panels were tested with the various finishes shown in Table 39. Erosion-resistance data generated by MCAIR and also shown in Table 29 indicates that none of the finishes performed better than the IVD aluminum-baseline finish. Additionally, most of the Table 39 protection finishes resulted in thicknesses that may be too thick for applications where a thinner (0.005-0.007 inch) finish is desired.

The application of the Zylan 1010 topcoat did improve the erosion resistance of the IVD aluminum basecoat. Although the topcoat material itself was removed readily by the glass beads, Table 39 shows that the erosion rate of the sealed-aluminum basecoat was improved in relation to the Table 37 baseline rate at both 40 and 60 psi.

TABLE 39. EROSION RESISTANCE OF TOPCOATED IVD ALUMINUM AND METALLIC-CERAMIC TYPE COATING.

Protective Finish	Erosion Rate (mils/second) Based On			
	Total Coating Thickness		IVD Aluminum Thickness	
	40 psi	60 psi	40 psi	60 psi
Topcoated IVD Aluminum				
Whitford Corporation				
Xylan 1010	0.0066	0.0130	0.0028	0.0056
Xylan 1331	0.0150	0.0355	0.0052	0.0102
Xylan 1840	0.0067	0.0239	0.0035	0.0124
Metallic-Ceramic Coatings				
Whitford Corporation				
Xylar 1	1.4606	1.9000		
Sermatech International, Inc.				
Sermetel CR 962	0.0459	0.1600		
Sermetel CR 984LT	0.4955	0.8571		
Sermatech XP 901213	0.0460	0.0574		
Coatings for Industry				
Alseal 518	0.7415	0.7500		

D. SUPPORTING EROSION RESISTANCE DATA

Pratt & Whitney (P&W) compared the erosion resistance of IVD aluminum and diffused nickel-cadmium finished compressor vanes by measuring the thickness of the two finishes after exposing the vanes to a liquid abrasive (Reference 21).

Erosion testing was performed at room temperature using a silicon oxide abrasive at an impingement angle of 90 degrees for 1 minute intervals. The pressure was held at 80 psi at a target distance of six inches.

The IVD aluminum coating eroded faster than the diffused nickel-cadmium plating. Table 40 tabulates the results of the test.

TABLE 40. IVD ALUMINUM AND DIFFUSED NICKEL-CADMIUM FINISH THICKNESS AFTER ABRASIVE EXPOSURE.

	Location	Thickness (mils)		
		0 min	1 min	2 min
IVD	A	1.0	0.9	0.2
	B	1.7	1.6	1.5
	C	1.8	1.8	1.4
	D	0.4	0.3	0
	E	0.7	0.7	0.4
	F	0.4	0.4	0.1
	G	1.3	1.2	0.8
	H	2.0	1.9	1.7
	J	2.2	1.8	1.6
NiCd	A	0.3	0.2	0.2
	B	0.8	0.5	0.5
	C	0.7	0.8	0.6
	D	0.1	0.1	0
	E	0.2	0.1	0.1
	F	0.2	0.1	<0.1
	G	0.5	0.3	0.5
	H	0.7	0.7	0.6
	J	0.6	0.7	0.6

In other tests conducted by P&W (Reference 22), IVD aluminum with a standard chromate conversion coating was shown to erode faster than the combination coating of diffused nickel-cadmium. However, because the IVD aluminum coating was applied thicker (1.5 mils vs 0.7 mils), there was adequate IVD aluminum remaining at the conclusion of the test. More importantly, IVD aluminum provided better protection to the substrate as the erosion process occurred. With diffused nickel-cadmium, the cadmium erodes very rapidly, leaving only the nickel coating which offers no anodic protection to the substrate. In fact, the Reference 22 testing by P&W showed IVD aluminum to be the best coating tested on 410-alloy steel. Specifically, IVD aluminum outperformed both diffused nickel-cadmium and Emplate nickel-422/cadmium in an erosion/corrosion environment. This was true for IVD aluminum samples supplied both with and without a standard chromate conversion coating, and a sample supplied with a Chromalloy proprietary conversion coating.

E. DISCUSSION

The data generated by MCAIR once again verified that IVD aluminum is not as erosion resistant as diffused nickel-cadmium.

However, IVD aluminum can be functionally applied several times thicker than diffused nickel-cadmium. Aluminum coating can actually be applied to thicknesses of 0.0020-0.0030 without a build-up of stresses on the part edge. Diffused nickel-cadmium is usually limited to 0.0005-0.0007 inch. Additionally, supporting data indicates that IVD aluminum is superior to diffused nickel-cadmium in the critical areas of corrosion and erosion-corrosion resistance.

It should also be noted that the difference in erosion resistance between the two finishes was not expressed as a major ALC concern as were coverage of internal surfaces and torque-tension characteristics. In fact, the SA-ALC has concurrence from Allison to substitute aluminum for cadmium on non-threaded T-56 engine details (Reference 9).

Although the various topcoats/sealcoats evaluated by MCAIR did not improve erosion resistance, an IVD aluminum alloy evaporant containing 12 percent silicon did improve the baseline when subjected to a peen pressure of 40 psi.

There were some abnormalities in the data generated by MCAIR particularly in relation to existing data for the metallic ceramic paint-type coatings. It is recognized that these coatings are currently in use by the ALCS for engine applications, and that their use has OEM concurrence. It is also recognized that different abrasive medium, pressures, impingement angles, etc. all have different effects on erosion resistance of the various protection systems.

F. CONCLUSION

The erosion resistance difference between IVD aluminum and diffused nickel-cadmium finishes is minimized by the capability of applying a thicker finish with the IVD process.

Where finish thickness tolerance is critical, the use of an aluminum evaporant containing 12 percent silicon improves performance over the 1100 aluminum alloy evaporant.

SECTION VI

CONCLUSION

Phase I of this program reviewed detail parts processed with cadmium at the ALCs. It concluded that approximately 80 percent of the parts could be processed with IVD aluminum without concern and identified those parts for which there was some concern.

Phase II addressed those areas of concern. Both barrier- and sacraficial-type protection systems that can be used to supplement the use of IVD aluminum for applications involving internal surfaces are identified in this report. Torque-tension data generated for such ALC concerns as wheel tie-bolts and engine bolts can also be found in this report. The data indicates that these bolts can be refurbished with IVD aluminum by the ALCs with little to no concern. For applications that now require diffused nickel-cadmium for erosion resistance, it is suggested that a thick IVD aluminum coating (0.0015-0.0025 inch) be used to compensate for differences in erosion rates.

The contents of the Phase I database handbook (Reference 1) and of this report indicate that IVD aluminum can replace cadmium processing at the ALCs. Although this substitution may involve additional processing steps and/or minor functional degradation for a small percent of the ALC applications, MCAIR believes that the overall benefit far exceeds the few limitations.

IVD aluminum coating has successfully undergone extensive laboratory and in-service testing as a substitute for cadmium -- many of those tests results are documented in Reference 1. IVD aluminum is an excellent corrosion resistant finish which offers performance advantages over cadmium for most applications. Because the IVD aluminum operation is clean, simple, and non-labor intensive, and because facility and space requirements are minimal and require no special pollution-related systems, it is a cost-competitive process. Cadmium costs are increasing because of environmental and health related laws and regulations. At the same time, IVD aluminum costs are decreasing because of productivity advances associated with its increased usage. Most importantly, aluminum is nontoxic, and the IVD process is environmentally clean.

MCAIR looks forward to the Phase III demonstration of the IVD aluminum process at the WR-ALC. It will be conducted with a state-of-the-art coating system procured during Phase II. It is projected that the Phase III demonstration will strongly support the elimination of hazardous waste producing cadmium processing at WR.

SECTION VII

PHASE III DEMONSTRATION

MCAIR will demonstrate the applicability of IVD aluminum at WR during Phase III of the program as an across-the-board replacement for all detail parts that are now processed by WR with cadmium.

MCAIR has proposed that a "hands-on" strategy be employed at the WR-ALC to implement the usage of IVD aluminum. "Hands-on" coordination with responsible departments was used successfully to implement the usage of the then new process at MCAIR. During Phase III:

- Supplemental processing needs such as part preclean processing equipment, special coater hooks and fixtures to increase throughput, post-coat processing equipment, and supplemental processing equipment will be reviewed and coordinated with Industrial Engineering at WR.

- Activities such as reviewing drawings/parts, defining coating thickness classes, identifying supplemental processing needs, and reviewing process specifications will be coordinated with WR Material Management.

- Quality Assurance guidelines will be coordinated with WR by reviewing and defining acceptance performance requirements, test procedures and equipment needs.

- WR Manufacturing will be assisted in demonstrating the feasibility of applying IVD aluminum to any and/or all WR detail parts that are now processed with cadmium over a four month period of time. This time period should provide adequate part selection, maximum training, and verification of coating conformance to MIL-C-83488. This effort will include establishment of coating procedure cards for individual detail parts to promote repeatability. Productivity gains attributable to the use of a state-of-the-art coater and special holding fixtures, like that designed for the C130 Propeller Hub, will also be established.

o Environmental compliance progress will be verified with WR Environmental Engineering.

MCAIR believes that the effort at WR will justify elimination of cadmium processing at that facility.

While it is planned to bring all of the ALCs together during the WR program, there are distinct divergencies of ALC responsibility as well as different "areas of concern" in substituting for cadmium. To address these areas, MCAIR also recommends that the other four ALCs be given some individual attention to help meet the ultimate goal of the elimination of cadmium processing at all of the ALCs.

MCAIR has proposed that applicable supplemental processing be reviewed with the other four ALCs. This effort would include recommendations for specific applications and a review of environmental compliance considerations. A program would also be coordinated with each of the other four ALCs in which procedures developed during Phase II of the program and/or those demonstrated at WR will be demonstrated on a minimum of five mutually acceptable detail parts for each of the ALCs. An acceptable demonstration site will be coordinated with each of the ALCs. This task will also include as much "hands-on" coordination as the budget allows.

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APPENDIX A

TORQUE-TENSION DATA FOR GENERIC BOLT-NUT WITH DIFFERENT BOLT FINISH - NUT FINISH - LUBRICANT COMBINATIONS

TABLE A-1. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
1	1	38	96	180	250	335	445	530	600	660	480	33
	2					290				660		
	3					300				660		
	4					265				600		
	5	33	96	144	190	275	360	430	580	600	360	35
	6					275				600		
	7					2				600		
	8					265				600		
	9					265				600		
	10	35	108	168	230	300	395	520	540	660	385	38
	11					275				600		
	12					300				660		
	13					265				600		
	14					290				660		
	15	34	108	168	230	310	410	530	540	660	410	37

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average plating thickness – 0.4987 in., average plating thickness – 0.00030 in.
47FLW-620 nut: Average plating thickness – 0.00041 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb

TABLE A-2. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
2	1	53	120	180	265	335	410	480	540	660	395	43
	2					310				660		
	3					300				660		
	4					290				660		
	5	42	108	156	230	290	370	480	540	660	395	45
	6					290				660		
	7					290				660		
	8					290				660		
	9					290				660		
	10	46	108	168	230	300	385	480	540	660	410	43
	11					290				660		
	12					290				660		
	13					300				660		
	14					300				660		
	15	43	108	168	230	300	385	470	540	660	395	44

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average plating thickness – 0.00043 in.
47FLW-620 nut: Average plating thickness – 0.00039 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb.

TABLE A-3. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
3	1	33	108	156	240	325	370	460	600	720	430	31
	2					290				660		
	3					240				600		
	4					240				600		
	5	29	96	144	205	240	350	430	480	600	350	32
	6					250				600		
	7					240				600		
	8					240				600		
	9					240				600		
	10	36	96	156	204	265	350	430	480	600	360	36
	11					250				600		
	12					250				600		
	13					250				600		
	14					250				600		
	15	42	120	180	240	300	395	470	540	660	370	37

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average plating thickness – 0.4985 in., average plating thickness – 0.00035 in.
47FLW-820 nut: Average plating thickness – 0.00038 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb.

TABLE A-4. TORQUE-TENSION TEST DATA FOR IVD ALUMIMUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INC. C-301-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
4	1	128	192	300	360	430	530	600	660	780	580	37
	2					420				840		
	3					340				780		
	4					360				780		
	5	43	108	204	252	360	470	600	660	780	520	41
	6					320				780		
	7					300				720		
	8					300				720		
	9					300				720		
	10	35	96	168	216	290	420	500	540	720	470	37
	11					290				720		
	12					310				720		
	13					300				660		
	14					280				660		
	15	32	96	156	228	300	420	520	600	720	430	37

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00058 in.
47FLW-820 nut: Average coating thickness – 0.00047 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb.

TABLE A-5. TORQUE-TENSION TEST DATA FOR IVD ALUMIMUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
5	1	127	228	276	340	410	480	540	600	720	520	124
	2					360				720		
	3					350				720		
	4					340				720		
	5	52	120	192	252	320	430	530	600	720	430	6
	6					310				720		
	7					310				660		
	8					320				660		
	9					310				660		
	10	45	96	156	204	290	370	470	540	660	400	55
	11					300				660		
	12					280				660		
	13					290				660		
	14					280				660		
	15	43	96	168	240	290	400	480	540	660	410	50

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4966 in., average coating thickness – 0.00049 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb.

TABLE A-6. TORQUE-TENSION TEST DATA FOR IVD ALUMIMUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
6	1	111	216	300	350	460	540	600	720	840	580	95
	2					400				780		
	3					350				780		
	4					340				720		
	5	38	120	192	290	320	410	490	480	660	430	47
	6					300				660		
	7					300				660		
	8					300				660		
	9					300				660		
	10	33	108	180	232	300	400	470	540	660	410	39
	11					300				720		
	12					290				660		
	13					290				660		
	14					290				660		
	15	36	108	168	260	300	410	480	540	660	400	36

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00055 in.
47FLW-820 nut: Average coating thickness – 0.00053 in.

d Torque increments of 60 in.-lb at maximum bolt load is larger than normal increments of 25 in.-lb

TABLE A-7. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
7	1	38	88	145	225	305	385	460	550	650	360	34
	2					275				650		
	3					260				700		
	4					250				675		
	5	34	91	141	200	270	345	450	565	675	380	33
	6					250				675		
	7					250				700		
	8					260				700		
	9					265				700		
	10	34	91	143	200	260	350	450	575	700	390	34
	11					270				700		
	12					265				700		
	13					265				700		
	14					260				700		
	15	31	84	136	200	265	355	455	575	700	400	37

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00030 in.
47FLW-820 nut: Average coating thickness – 0.00049 in.

d There was one stop at 10,000 lb instead of each load increment, as normally done, for cycles 1, 5, 10 and 15.

TABLE A-8. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
8	1	36	91	136	190	270	330	415	495	580	320	27
	2					240				675		
	3					260				675		
	4					290				700		
	5	33	81	132	190	265	355	450	590	675	320	31
	6					275				650		
	7					320				675		
	8					325				675		
	9					285				675		
	10	36	84	136	250	305	395	460	565	650	290	35
	11					305				650		
	12					305				650		
	13					315				650		
	14					310				650		
	15	34	86	141	205	275	360	450	535	650	340	35

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.000 in.

d Test was a repeat of test 1 with optimized procedure and equipment.

TABLE A-9. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
9	1	51	106	175	245	320	400	475	550	650	355	47
	2					285				625		
	3					245				625		
	4					240				625		
	5	41	90	145	205	275	340	425	520	625	320	46
	6					255				650		
	7					250				650		
	8					250				650		
	9					255				625		
	10	51	102	150	200	255	330	430	540	650	335	51
	11					270				625		
	12					255				625		
	13					265				600		
	14					250				600		
	15	46	75	150	215	275	350	435	520	625	325	58

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00033 in.
47FLW-820 nut: Average coating thickness – 0.0037 in.

d Test was a repeat of test 2 with optimized procedure and equipment.

TABLE A-10. TORQUE-TENSION TEST DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INC. C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
10	1	54	113	175	250	320	405	490	590	700	405	45
	2					305				700		
	3					300				700		
	4					295				700		
	5	54	115	170	240	310	390	485	600	700	420	58
	6					285				675		
	7					285				675		
	8					285				675		
	9					280				675		
	10	58	107	155	210	285	370	475	570	675	390	59
	11					275				675		
	12					275				650		
	13					275				650		
	14					280				650		
	15	55	112	165	225	300	380	490	600	675	360	61

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average plating thickness – 0.00035 in.
47FLW-820 nut: Average plating thickness – 0.00042 in.

d Test was a repeat of test 3 with optimized procedure and equipment.

TABLE A-11. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
11	1	93	180	250	335	435	530	650	775	900	625	89
	2					405				850		
	3					385				850		
	4					340				825		
	5	37	123	205	290	370	475	600	725	875	600	42
	6					340				875		
	7					325				850		
	8					300				825		
	9					305				825		
	10	31	111	160	225	315	405	515	650	800	475	33
	11					305				800		
	12					300				775		
	13					290				750		
	14					275				700		
	15	33	83	139	205	275	385	490	650	750	440	27

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00045 in.
47FLW-820 nut: Average coating thickness – 0.00047 in.

d Test was a repeat of test 4 with optimized procedure and equipment.

TABLE A-12. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
12	1	160	250	335	370	510	650	725	850	950	700	141
	2					390				825		
	3					360				750		
	4					330				725		
	5	46	117	160	250	330	445	525	625	725	445	49
	6					285				700		
	7					280				700		
	8					285				700		
	9					280				700		
	10	36	98	185	250	325	415	505	625	725	450	46
	11					285				725		
	12					275				700		
	13					275				700		
	14					275				675		
	15	38	103	185	225	290	385	485	595	700	410	33

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4987 in., average coating thickness – 0.00047 in.
47FLW-820 nut: Average coating thickness – 0.00044 in.

d Test was a repeat of test 5 with optimized procedure and equipment.

TABLE A-13. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
13	1	113	185	265	325	425	510	625	700	825	550	118
	2					370				800		
	3					340				800		
	4					370				800		
	5	53	121	175	250	335	425	545	650	775	485	52
	6					310				750		
	7					340				750		
	8					345				750		
	9					320				700		
	10	52	107	155	250	315	400	490	600	700	415	45
	11					320				725		
	12					305				700		
	13					300				700		
	14					285				700		
	15	34	91	155	220	295	380	480	600	700	410	43

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00041 in.
47FLW-820 nut: Average coating thickness – 0.00065 in.

d Test was a repeat of test 6 with optimized procedure and equipment.

TABLE A-14. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
14	1	44	101	160	215	295	355	440	505	575	305	59
	2					300				675		
	3					330				700		
	4					320				700		
	5	61	121	195	270	335	410	510	625	725	425	60
	6					315				700		
	7					305				700		
	8					300				675		
	9					300				675		
	10	36	114	185	255	330	410	495	600	675	390	48
	11					305				650		
	12					300				675		
	13					305				675		
	14					305				675		
	15	41	103	175	240	310	385	490	600	700	410	46

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00050 in.
47FLW-820 nut: Average coating thickness – 0.00042 in.

d Test was an evaluation of different bolt and nut finishes and the torquing procedure. There was one stop at 10,000 pounds instead of each load increment, as normally done, for cycles 1, 5, 10, and 15.

TABLE A-15. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
15	1	34	95	160	230	310	395	465	550	675	360	33
	2					320				775		
	3					320				800		
	4					325				800		
	5	51	107	170	250	330	425	520	650	775	455	52
	6					285				725		
	7					260				700		
	8					280				675		
	9					275				675		
	10	39	89	133	205	275	355	460	560	675	360	41
	11					265				650		
	12					260				650		
	13					265				650		
	14					255				650		
	15	36	84	130	200	265	360	455	550	650	350	31

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00043 in.
47FLW-620 nut: Average coating thickness – 0.00050 in.

d Test was an evaluation of different bolt and nut finishes with optimized procedure and equipment.

TABLE A-16. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
16	1	64	123	195	255	315	390	460	530	625	315	67
	2					325				675		
	3					335				725		
	4					335				725		
	5	74	139	210	275	340	420	520	625	725	420	69
	6					330				700		
	7					310				675		
	8					300				675		
	9					295				650		
	10	49	106	180	230	305	380	470	555	675	365	47
	11					290				650		
	12					285				650		
	13					285				650		
	14					285				650		
	15	46	101	165	220	290	365	460	545	650	350	41

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4989 in., average coating thickness – 0.00046 in.
47FLW-620 nut: Average coating thickness – 0.00044 in.

d Test was an evaluation of different bolt and nut finishes with optimized procedure and equipment.

TABLE A-17. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
17	1	53	111	165	235	310	380	465	550	650	350	59
	2					330				775		
	3					380				725		
	4					350				750		
	5	63	128	195	285	350	430	530	650	750	440	79
	6					320				750		
	7					300				700		
	8					275				700		
	9					285				700		
	10	46	97	150	210	275	350	450	555	700	415	62
	11					265				700		
	12					275				700		
	13					270				700		
	14					265				675		
	15	45	98	150	205	275	360	470	585	700	390	48

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00043 in.
47FLW-820 nut: Average coating thickness – 0.00035 in.

d Test was an evaluation of different bolt and nut finishes with optimized procedure and equipment.

TABLE A-18. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
18	1	103	190	265	335	415	510	625	700	800	490	92
	2					350				875		
	3					355				875		
	4					410				875		
	5	48	116	190	270	345	445	550	675	825	510	61
	6					350				825		
	7					325				800		
	8					340				800		
	9					340				775		
	10	48	110	170	245	340	435	495	650	775	470	47
	11					345				750		
	12					325				725		
	13					320				725		
	14					310				725		
	15	34	95	155	235	320	395	485	625	725	420	41

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00045 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

d Test was an evaluation of an IVD aluminum- and carbowax-coated nut and the torquing procedure. There was one stop at 10,000 pounds instead of each load increment, as normally done, for cycles 1, 5, 10, and 15.

TABLE A-19. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
19	1	73	132	205	285	370	460	545	650	750	450	76
	2					355				800		
	3					365				800		
	4					345				775		
	5	30	113	185	275	355	460	560	675	800	485	29
	6					315				775		
	7					310				750		
	8					305				775		
	9					305				750		
	10	21	95	150	240	330	410	515	625	750	445	20
	11					300				725		
	12					285				700		
	13					260				700		
	14					255				675		
	15	18	82	134	200	285	380	485	600	700	400	17

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4967 in., average coating thickness – 0.00047 in.
47FLW-820 nut: Average coating thickness – 0.00044 in.

d Test was an evaluation of an IVD aluminum- and carbowax-coated nut with optimized procedure and equipment.

TABLE A-20. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
20	1	84	132	190	270	340	440	520	650	725	440	91
	2					325				800		
	3					335				800		
	4					315				775		
	5	39	100	155	230	320	420	525	650	775	475	42
	6					315				725		
	7					290				725		
	8					300				725		
	9					265				700		
	10	36	96	150	230	295	380	475	570	700	405	36
	11					305				700		
	12					310				700		
	13					270				700		
	14					270				700		
	15	34	87	145	215	295	370	460	555	675	375	34

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4967 in., average coating thickness – 0.00043 in.
47FLW-820 nut: Average coating thickness – 0.00051 in.

d Test was an evaluation of an IVD aluminum- and carbowax-coated nut with optimized procedure and equipment.

TABLE A-21. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
21	1	77	133	190	255	335	415	500	600	700	425	68
	2					315				750		
	3					315				750		
	4					300				750		
	5	42	104	142	210	295	3[illegible]	[illegible]80	580	700	425	21
	6					290				725		
	7					285				700		
	8					300				700		
	9					280				700		
	10	45	93	147	205	295	365	465	570	700	415	17
	11					265				675		
	12					260				675		
	13					255				675		
	14					285				650		
	15	34	85	149	200	265	345	435	530	650	350	13

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4968 in., average coating thickness – 0.00048 in.
47FLW-820 nut: Average coating thickness – 0.00049 in.

d Test was an evaluation of an IVD aluminum- and carbowax-coated nut with optimized procedure and equipment.

TABLE A-22. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
22	1	110	175	205	270	355	440	555	675	775	495	115
	2					345				800		
	3					325				750		
	4					335				750		
	5	45	115	175	235	325	420	515	625	725	440	45
	6					275				700		
	7					275				725		
	8					280				700		
	9					270				700		
	10	40	105	165	225	300	385	475	600	700	425	40
	11					270				700		
	12					260				700		
	13					255				725		
	14					245				725		
	15	35	100	145	195	270	355	460	580	750	440	35

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4965 in., average coating thickness – 0.00032 in.
47FLW-820 nut: Average coating thickness – 0.00044 in.

d Test was to evaluate the procedure for applying the lubricant onto the bolt and carbowax-coated nut.

TABLE A-23. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
23	1	102	180	260	335	435	550	650	750	850	650	117
	2									775		
	3									700		
	4									700		
	5	43	110	170	230	305	385	485	580	700	430	42
	6									675		
	7									675		
	8									650		
	9									650		
	10	33	83	125	180	250	330	435	560	675	395	37
	11									625		
	12									625		
	13									625		
	14									600		
	15	31	68	127	185	255	325	485	535	650	390	33

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00046 in.
47FLW-620 nut: Average coating thickness – 0.00051 in.

d Test was evaluation of torquing procedure. There was a stop at 10,000 pounds to record torque applied to nut for cycles 1, 5, 10, and 15 and no stop at 10,000 pounds for all other torque-tension cycles.

TABLE A-24. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
24	1	117	175	245	320	400	490	590	700	825	545	118
	2									825		
	3									825		
	4									825		
	5	56	116	170	235	315	410	520	650	775	470	52
	6									725		
	7									725		
	8									725		
	9									725		
	10	41	92	145	220	295	380	470	560	700	405	43
	11									700		
	12									675		
	13									675		
	14									675		
	15	39	84	134	200	280	355	450	540	675	365	41

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00050 in.
47FLW-620 nut: Average coating thickness – 0.00056 in.

d Test was evaluation of torquing procedure. There was a stop at each load increment to record torque applied to nut for cycles 1, 5, 10, and 15 and no stop at 10,000 pounds for all other torque-tension cycles.

TABLE A-25. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
25	1	107	175	245	330	410	510	625	725	850	570	96
	2									850		
	3									775		
	4									775		
	5	42	114	170	260	345	435	540	650	800	525	43
	6									750		
	7									750		
	8									750		
	9									775		
	10	37	109	155	230	310	400	510	650	750	475	39
	11									925		
	12									800		
	13									750		
	14									725		
	15	33	103	165	230	315	410	520	650	750	455	33

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00041 in.
47FLW-820 nut: Average coating thickness – 0.00051 in.

d Test was evaluation of torquing procedure. There was a stop at each load increment to record torque applied to nut for cycles 1, 5, 10, and 15 and no stop at 10,000 pounds for all other torque-tension cycles.

TABLE A-26. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
26	1	96	160	235	310	400	505	595	650	775	495	103
	2									775		
	3									775		
	4									750		
	5	38	106	165	235	315	410	525	650	775	495	37
	6									775		
	7									725		
	8									700		
	9									700		
	10	34	96	155	220	305	415	515	650	750	450	34
	11									700		
	12									700		
	13									700		
	14									675		
	15	32	92	145	205	275	365	475	585	725	420	34

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00048 in.
47FLW-820 nut: Average coating thickness – 0.00049 in.

d Test was evaluation of torquing procedure. There was a stop at each load increment to record torque applied to nut for cycles 1, 5, 10, and 15 and no stop at 10,000 pounds for all other torque-tension cycles.

TABLE A-27. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND IVD ALUMINUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
27	1	40	95	145	215	290	365	445	535	625	360	30
	2					255				600		
	3					235				560		
	4					215				575		
	5	25	80	125	170	230	310	400	495	585	340	20
	6					230				575		
	7					230				600		
	8					245				555		
	9					250				600		
	10	30	90	140	190	250	320	410	495	600	320	30
	11					280				650		
	12					200				650		
	13					275				625		
	14					260				625		
	15	35	110	160	220	285	365	450	555	675	370	

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00039 in.
47FLW-820 nut: Average coating thickness – 0.00049 in.

d Test was an evaluation of dissimilar finishes on the bolt and nut with optimized procedure and equipment.

TABLE A-28. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND IVD ALUMINUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
28	1	60	120	180	240	320	395	470	570	675	390	40
	2					265				650		
	3					270				625		
	4					270				625		
	5	50	105	165	225	305	385	470	565	650	365	50
	6					300				675		
	7					280				675		
	8					270				650		
	9					270				650		
	10	55	115	170	225	290	365	460	565	650	360	60
	11					275				650		
	12					270				650		
	13					280				675		
	14					275				675		
	15	60	115	170	225	295	380	480	595	700	405	70

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00040 in.
47FLW-820 nut: Average coating thickness – 0.00049 in.

d Test was an evaluation of dissimilar finishes on the bolt and nut with optimized procedure and equipment.

TABLE A-29. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND IVD ALUMINUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
29	1	45	95	150	200	265	300	415	495	580	315	30
	2					225				550		
	3					230				570		
	4					220				545		
	5	35	85	135	190	245	325	405	485	575	300	30
	6					265				585		
	7					230				575		
	8					275				600		
	9					285				625		
	10	40	100	165	230	280	360	440	530	650	335	35
	11					275				650		
	12					290				650		
	13					275				675		
	14					290				675		
	15	40	105	165	215	290	385	460	555	650	360	45

a. Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c. NAS1308-10 bolt. Average shank diameter – 0.4990 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00048 in.

d. Test was an evaluation of dissimilar finishes on the bolt and nut with optimized procedure and equipment.

TABLE A-30. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
30	1	110	210	280	355	440	530	650	750	850	565	100
	2					415				825		
	3					310				750		
	4					300				750		
	5	55	120	175	230	310	395	510	650	775	480	50
	6					295				750		
	7					290				775		
	8					305				750		
	9					285				750		
	10	40	105	165	220	310	400	515	650	750	480	40
	11					280				725		
	12					275				725		
	13					260				725		
	14					260				725		
	15	40	95	150	210	285	390	495	625	750	460	40

a. Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c. NAS1308-10 bolt. Average shank diameter – 0.4988 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

d. Test was an evaluation of the IVD aluminum coating applied to the bolt. Bolt was tested as coated. Normally all bolts and nuts were glass bead peened and chemical conversion coated.

TABLE A-31. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
31	1	120	170	255	350	445	545	650	750	875	625	115
	2					360				825		
	3					365				750		
	4					295				725		
	5	45	110	160	225	305	390	480	600	725	490	55
	6					340				750		
	7					320				725		
	8					260				700		
	9					250				700		
	10	45	95	155	200	265	365	470	580	700	470	40
	11					270				725		
	12					270				700		
	13					280				750		
	14					280				725		
	15	40	105	165	225	295	390	495	625	725	475	35

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00031 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

d Test was to evaluate the effect of a polished IVD aluminum coating on the torque-tension characteristics of the bolt and nut.

TABLE A-32. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
32	1	85	155	220	280	355	440	535	650	750	440	90
	2					310				725		
	3					290				725		
	4					340				775		
	5	40	110	190	260	330	425	525	650	750	455	50

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4982 in., average coating thickness – 0.00015 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

d Test was an evaluation of a very thin IVD aluminum coating on the bolt and a normal thickness of IVD aluminum coating on the nut.

TABLE A-33. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
33	1	90	140	200	270	365	440	535	650	750	445	85
	2					385				825		
	3					355				800		
	4					355				825		
	5	60	125	195	265	355	460	580	700	825	535	

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4983 in., average coating thickness – 0.00018 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

d Test was an evaluation of a very thin IVD aluminum coating on the bolt and a normal thickness of IVD aluminum coating on the nut. In addition, any metal particle contamination in the lubricant was removed by ultrasonically cleaning the bolt and nut after the first torque-tension cycle.

TABLE A-34. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
34	1	85	125	190	265	350	440	535	650	750	450	80
	2					340				800		
	3					310				750		
	4					300				775		
	5	40	85	150	215	300	405	520	650	775	500	40

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00048 in.

d Test was to evaluate the effect of multiple applications of carbowax on the bolt/nut torque-tension characteristics. The carbowax was applied to the bolt and nut.

TABLE A-35. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
35	1	90	140	210	285	370	460	555	650	750	480	85
	2					350				800		
	3					355				800		
	4					340				750		
	5	50	105	165	245	320	405	510	625	750	450	45

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4880 in., average coating thickness – 0.00018 in.
47FLW-820 nut: Average coating thickness – 0.00026 in.

d Test was an evaluation of a very thin IVD aluminum coating on the bolt and nut. In addition, any metal particle contamination in the lubricant was removed by ultrasonically cleaning the bolt and nut after the first torque-tension cycle.

TABLE A-36. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
36	1	50	110	175	260	345	430	535	650	750	460	60
	2					370				875		
	3					450				900		
	4					360				850		
	5	40	115	200	285	380	490	600	750	900	625	40

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4884 in., average coating thickness – 0.00017 in.
47FLW-820 nut: Average coating thickness – 0.00031 in.

d Test was an evaluation of a very thin IVD aluminum coating on the bolt and nut. In addition, any metal particle contamination in the lubricant was removed by ultrasonically cleaning the bolt and nut after the first torque-tension cycle.

TABLE A-37. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
37	1	50	110	185	265	360	460	555	675	800	510	60
	2					295				725		
	3					290				775		
	4					285				900		
	5	40	85	140	200	270	350	475	595	725	470	40
	6					270				800		
	7					270				800		
	8					265				800		
	9					270				850		
	10	30	115	190	265	355	480	625	775	900	600	30
	11					295				850		
	12					260				800		
	13					260				775		
	14					260				750		
	15	20	80	120	190	255	350	465	625	750	445	25

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00042 in.
47FLW-820 nut: Average coating thickness – 0.00048 in.

d Test was an evaluation of an IVD aluminum-zinc coating from an aluminum alloy containing 20% zinc. The aluminum-zinc-coated bolt and nut were glass bead peened and chemically conversion coated.

TABLE A-38. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
38	1	100	175	240	330	415	505	625	725	825	560	80
	2					335				800		
	3					305				800		
	4					300				800		
	5	40	95	155	215	295	390	515	650	800	520	40
	6					295				825		
	7					300				850		
	8					290				850		
	9					290				800		
	10	30	85	135	200	270	370	500	625	775	480	30
	11					270				750		
	12					265				750		
	13					250				700		
	14					250				700		
	15	30	80	135	180	260	350	465	590	725	410	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00044 in.
47FLW-820 nut: Average coating thickness – 0.00047 in.

d Test was an evaluation of an IVD aluminum-zinc coating from an aluminum alloy containing 20% zinc. The aluminum-zinc-coated bolt and nut were glass bead peened and chemically conversion coated. In addition, carbowax was applied to the aluminum-zinc-coated nut.

TABLE A-39. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
39	1	56	113	180	260	335	455	525	650	775	565	52
	2					360				950		
	3					365				950		
	4					370				975		
	5	48	112	170	260	370	500	650	825	975	700	50
	6					360				1,000		
	7					350				975		
	8					350				975		
	9					335				925		
	10	29	105	170	250	335	450	625	725	875	600	38
	11					320				850		
	12					315				800		
	13					305				850		
	14					325				850		
	15	31	93	170	255	380	465	575	700	825	625	36

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4968 in., average coating thickness – 0.00040 in.
47FLW-820 nut. Average coating thickness – 0.00043 in.

TABLE A-40. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
40	1	53	109	180	255	325	415	525	650	725	550	39
	2					375				925		
	3					355				975		
	4					375				975		
	5	43	111	180	270	380	510	675	850	1,000	750	43
	6					360				1,000		
	7					370				975		
	8					345				950		
	9					355				925		
	10	36	102	165	235	330	455	550	750	850	625	32
	11					315				850		
	12					320				825		
	13					375				825		
	14					325				800		
	15	33	95	170	255	330	425	500	625	750	575	27

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4987 in., average coating thickness – 0.00041 in.
47FLW 820 nut. Average coating thickness – 0.00042 in.

TABLE A-41. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
41	1	67	131	205	295	390	485	600	725	875	625	52
	2					325				950		
	3					345				1,000		
	4					355				1,000		
	5	61	121	195	280	375	535	675	825	975	700	57
	6					360				950		
	7					335				900		
	8					330				850		
	9					330				900		
	10	45	93	155	225	320	425	625	750	875	650	39
	11					300				850		
	12					295				825		
	13					280				800		
	14					270				775		
	15	37	96	155	215	285	385	575	650	800	550	31

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00037 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-42. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
42	1	89	190	270	350	460	575	750	950	1,075	825	69
	2					450				1,050		
	3					410				1,050		
	4					360				975		
	5	39	123	215	280	370	495	650	825	975	725	43
	6					485				1,150		
	7					410				1,050		
	8					375				1,000		
	9					345				950		
	10	32	104	185	250	355	480	625	800	975	700	31
	11					355				950		
	12					325				950		
	13					340				925		
	14					320				900		
	15	27	94	155	230	335	460	600	800	925	675	27

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00051 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-43. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
43	1	76	185	275	360	455	550	700	875	1,050	850	82
	2					470				1,100		
	3					445				1,125		
	4					380				1,050		
	5	36	100	185	300	420	505	700	800	1,000	775	36
	6					360				975		
	7					345				875		
	8					320				850		
	9					325				850		
	10	29	91	170	280	425	490	625	725	875	600	30
	11					315				825		
	12					325				825		
	13					320				825		
	14					310				750		
	15	29	84	160	240	330	450	550	650	800	525	24

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4989 in., average coating thickness – 0.00051 in.
47FLW-820 nut: Average coating thickness – 0.00053 in.

TABLE A-44. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-670.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
44	1	93	195	305	450	545	650	775	925	1,175	850	85
	2					450				1,050		
	3					430				1,000		
	4					415				975		
	5	26	107	195	260	345	460	625	700	900	650	24
	6					325				900		
	7					320				850		
	8					310				825		
	9					295				825		
	10	22	88	155	225	305	425	535	650	775	500	21
	11					315				825		
	12					310				800		
	13					300				800		
	14					300				800		
	15	20	84	150	220	305	410	525	725	800	525	19

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-670 lubricant contains 65% molybdenum disulfide suspended in a soft paste. The C-670 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00049 in.
47FLW-820 nut: Average coating thickness – 0.00048 in.

TABLE A-45. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
45	1	41	102	165	230	300	365	455	525	650	355	31
	2					290				650		
	3					280				650		
	4					270				650		
	5	35	86	140	215	290	340	415	510	625	325	36
	6					285				625		
	7					270				625		
	8					280				625		
	9					265				625		
	10	31	78	137	210	290	375	455	525	600	310	28
	11					275				600		
	12					275				600		
	13					270				600		
	14					270				575		
	15	27	81	144	205	290	350	440	530	600	290	26

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00031 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-46. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
46	1	47	111	170	245	310	395	475	575	650	375	43
	2					245				600		
	3					255				650		
	4					260				650		
	5	33	78	130	190	260	320	420	510	625	320	37
	6					240				625		
	7					245				650		
	8					245				650		
	9					245				650		
	10	31	87	115	180	255	335	435	520	650	345	38
	11					245				650		
	12					250				650		
	13					250				650		
	14					230				600		
	15	31	81	139	195	270	350	440	530	625	325	34

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00033 in.
47FLW-820 nut: Average coating thickness – 0.00041 in.

TABLE A-47. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
47	1	41	92	160	230	310	395	480	600	700	435	41
	2					250				625		
	3					245				600		
	4					240				600		
	5	31	87	140	195	240	315	395	490	590	303	35
	6					250				600		
	7					250				575		
	8					245				585		
	9					245				585		
	10	32	84	132	190	245	315	400	490	560	310	34
	11					230				590		
	12					240				575		
	13					230				555		
	14					225				560		
	15	32	77	124	180	235	305	380	475	570	265	29

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00031 in.
47FLW-820 nut. Average coating thickness – 0.00037 in.

TABLE A-48. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
48	1	118	210	300	375	460	550	650	750	875	575	88
	2					395				875		
	3					370				850		
	4					355				825		
	5	51	124	195	295	375	480	525	600	750	475	48
	6					330				775		
	7					320				750		
	8					310				750		
	9					305				725		
	10	36	98	155	240	325	435	540	650	725	440	34
	11					315				750		
	12					305				775		
	13					300				725		
	14					295				750		
	15	32	91	155	230	313	415	525	650	725	420	29

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00056 in.
47FLW-820 nut: Average coating thickness – 0.00052 in.

TABLE A-49. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
49	1	66	155	220	295	360	425	520	625	700	425	78
	2					355				750		
	3					325				725		
	4					325				725		
	5	43	115	160	220	290	375	460	565	675	370	41
	6					290				700		
	7					265				650		
	8					260				650		
	9					265				650		
	10	27	81	138	195	270	335	420	525	650	360	28
	11					255				650		
	12					250				625		
	13					250				650		
	14					250				650		
	15	23	71	122	185	250	340	415	530	650	335	26

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00043 in.
47FLW-820 nut: Average coating thickness – 0.00053 in.

TABLE A-50. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED MOLY-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
50	1	102	180	255	315	395	475	545	650	750	455	83
	2					355				750		
	3					320				700		
	4					300				650		
	5	43	113	165	240	310	395	500	650	700	420	46
	6					275				725		
	7					270				675		
	8					265				650		
	9					245				600		
	10	34	83	135	180	240	305	400	495	580	315	36
	11					230				570		
	12					240				575		
	13					235				595		
	14					235				575		
	15	31	86	142	175	235	305	395	455	565	290	32

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated Moly-50 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum formulated to meet MIL-T-83483. The Moly-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4988 in., average coating thickness – 0.00052 in.
47FLW-820 nut: Average coating thickness – 0.00051 in.

TABLE A-51. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
51	1	81	170	235	315	415	510	625	725	825	525	77
	2					470				1,075		
	3					675				>1,200		
	4					650				1,350		
	5	135	225	330	445	585	750	900	1,100	1,325	1,050	135
	6					575				1,275		
	7					550				1,200		
	8					480				1,075		
	9					390				975		
	10	90	175	245	325	420	540	700	800	950	650	110
	11					380				950		
	12					380				925		
	13					370				925		
	14					405				925		
	15	85	160	240	325	425	560	700	825	950	675	90

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00041 in.

TABLE A-52. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
52	1	55	125	210	305	405	525	700	800	925	775	55
	2					540				1,300		
	3					565				1,200		
	4					625				1,275		
	5	80	195	330	475	625	750	950	1,150	1,375	1,200	85
	6					525				1,250		
	7					460				1,025		
	8					415				975		
	9					370				900		
	10	35	115	215	295	395	470	580	750	875	650	40
	11					340				925		
	12					350				925		
	13					335				900		
	14					345				875		
	15	45	120	200	295	375	470	585	750	900	650	55

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00040 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-53. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
53	1	50	135	240	335	465	600	725	800	925	750	45
	2					510				1,150		
	3					575				1,250		
	4					625				1,350		
	5	75	200	340	475	625	800	1,025	1,225	1,450	1,225	70
	6					550				1,350		
	7					510				1,275		
	8					480				1,150		
	9					420				1,025		
	10	45	105	185	280	385	515	675	800	925	700	40
	11					350				950		
	12					345				900		
	13					315				875		
	14					315				875		
	15	35	95	180	300	415	540	625	750	850	575	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00042 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-54. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
54	1	160	290	405	535	675	850	1,025	1,175	–	875	200
	2					700				1,225		
	3					700				1,400		
	4					825				1,575		
	5	55	200	360	525	725	900	1,125	1,350	1,425	1,100	55
	6					650				1,300		
	7					600				1,200		
	8					530				1,150		
	9					495				1,125		
	10	38	131	220	320	440	600	825	950	1,025	725	40
	11					455				1,100		
	12					490				1,150		
	13					435				1,175		
	14					450				1,200		
	15	38	140	230	350	485	650	825	950	1,125	825	

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00041 in.
47FLW-820 nut: Average coating thickness – 0.00050 in.

TABLE A-55. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
55	1	185	335	500	650	775	950	1,100	1,275	1,450	1,250	165
	2					775				1,475		
	3					600				1,350		
	4					580				1,350		
	5	40	170	290	390	495	650	825	1,050	1,250	1,025	45
	6					520				1,200		
	7					480				1,200		
	8					505				1,200		
	9					435				1,075		
	10	30	125	200	295	400	500	725	875	1,025	750	30
	11					435				975		
	12					425				925		
	13					440				975		
	14					395				875		
	15	30	145	230	320	400	490	595	725	900	625	25

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4990 in., average coating thickness – 0.00050 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-56. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ROYAL LUBRICANTS COMPANY, INC. ROYCO 81MS.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
56	1	95	205	295	375	475	570	700	850	950	750	155
	2					525				1,100		
	3					600				1,300		
	4					600				1,350		
	5	27	165	305	475	545	675	850	1,050	1,325	1,050	35
	6					530				1,200		
	7					585				1,200		
	8					560				1,175		
	9					510				1,100		
	10	20	120	230	375	465	545	675	800	950	700	25
	11					415				950		
	12					420				925		
	13					410				875		
	14					420				900		
	15	20	110	210	310	455	510	600	725	850	550	20

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Royal Lubricants Company, Inc. Royco 81MS lubricant is a mixture basically 50% molybdenum disulfide and 50% silicone oil formulated to meet MIL-L-25681. The Royco 81MS lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00046 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

TABLE A-57. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-400.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
57	1	55	130	200	285	390	520	675	800	900	675	50
	2					405				950		
	3					420				950		
	4					400				900		
	5	50	115	190	290	425	540	675	775	925	675	50
	6					420				925		
	7					365				925		
	8					355				900		
	9					340				875		
	10	40	110	190	260	340	430	555	725	875	600	40
	11					310				825		
	12					370				800		
	13					360				800		
	14					310				750		
	15	40	105	165	255	365	455	540	675	775	485	50

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite Products Company GP-400 lubricant is a paste containing approximately 50% molybdenum disulfide, 5% graphite, and 40% mineral oil with a soap base thickener. The GP-400 lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt. Average shank diameter – 0.4987 in., average coating thickness – 0.00032 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-58. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-400.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
58	1	125	200	285	365	470	570	725	875	1,025	750	110
	2					455				1,075		
	3					410				1,100		
	4					425				1,050		
	5	45	115	195	280	390	510	675	825	950	700	40
	6					370				950		
	7					360				900		
	8					340				850		
	9					320				825		
	10	40	100	170	240	325	440	555	700	850	575	40
	11					310				850		
	12					300				800		
	13					300				800		
	14					305				800		
	15	35	100	165	230	315	410	525	650	800	510	40

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite Products Company GP-400 lubricant is a paste containing approximately 50% molybdenum disulfide, 5% graphite, and 40% mineral oil with a soap base thickener. The GP-400 lubricant was applied to the threads of the bolt and nut.

c NAS1306-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00048 in.

TABLE A-59. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-401.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
59	1	75	135	210	300	400	535	700	800	950	725	60
	2					295				750		
	3					290				800		
	4					285				775		
	5	50	110	170	230	310	420	530	675	800	570	45
	6					300				800		
	7					290				775		
	8					285				800		
	9					290				800		
	10	30	90	145	210	290	380	490	625	800	550	35
	11					275				800		
	12					275				775		
	13					270				775		
	14					265				775		
	15	30	95	145	205	275	360	455	580	750	485	35

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite Products Company GP-401 lubricant is a paste containing approximately 50% molybdenum disulfide, 5% graphite, and 40% mineral oil with a non soap base thickener. The GP-401 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00032 in.
47FLW-820 nut. Average coating thickness – 0.00039 in.

TABLE A-60. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-401.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
60	1	115	170	260	365	480	600	725	875	1,025	825	110
	2					395				950		
	3					360				925		
	4					330				900		
	5	35	90	160	230	310	415	535	675	825	575	40
	6					285				825		
	7					290				825		
	8					280				800		
	9					275				825		
	10	30	75	135	200	270	380	380	675	825	545	30
	11					260				775		
	12					270				800		
	13					275				775		
	14					255				750		
	15	20	70	125	185	265	360	360	650	775	450	25

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite Products Company GP-401 lubricant is a paste containing approximately 50% molybdenum disulfide, 5% graphite, and 40% mineral oil with a non soap base thickener. The GP-401 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-61. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-460.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Lead (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
61	1	45	95	160	245	355	465	570	650	750	465	35
	2					315				700		
	3					245				625		
	4					250				625		
	5	30	85	135	190	265	355	445	550	650	375	30
	6					255				650		
	7					270				675		
	8					285				700		
	9					270				700		
	10	40	95	140	200	275	385	480	585	700	410	40
	11					265				650		
	12					260				650		
	13					270				650		
	14					255				650		
	15	40	90	135	190	260	350	455	565	700	395	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite Products Company GP-460 lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The GP-460 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4968 in., average coating thickness – 0.00036 in.
47FLW-820 nut: Average coating thickness – 0.00036 in.

TABLE A-62. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD-ALUMINUM COATED NUT LUBRICATED WITH GRAPHITE PRODUCTS COMPANY GP-460.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Lead (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
62	1	125	205	295	380	485	600	700	800	925	700	120
	2					420				850		
	3					375				800		
	4					315				750		
	5	45	110	165	235	315	410	505	650	750	480	50
	6					310				750		
	7					300				750		
	8					285				750		
	9					280				775		
	10	40	105	160	230	305	405	515	675	825	545	50
	11					300				825		
	12					285				750		
	13					270				750		
	14					265				750		
	15	35	100	155	215	295	385	505	650	750	465	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Graphite products company GP-460 lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The GP-460 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00036 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-63. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION CP-28.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d] Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
63	1	70	125	200	295	405	520	650	800	950	700	50
	2					325				825		
	3					305				800		
	4					300				800		
	5	50	105	170	240	315	425	555	725	850	600	50
	6					285				800		
	7					280				800		
	8					290				800		
	9					275				775		
	10	40	95	160	235	315	415	520	675	800	560	45
	11					290				775		
	12					280				775		
	13					285				775		
	14					280				750		
	15	35	90	145	210	285	380	480	650	775	480	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M corporation CP-28 lubricant is a paste containing 60% molybdenum disulfide, an organic barium compound, mineral oil, and lithium grease. The CP-28 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00033 in.
47FLW-820 nut: Average coating thickness – 0.00037 in.

TABLE A-64. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD-ALUMINUM COATED NUT LUBRICATED WITH E/M CORPORATION CP-28.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d] Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
64	1	130	260	380	500	650	800	925	1,050	1,200	925	110
	2					450				1,025		
	3					455				1,000		
	4					410				975		
	5	40	135	215	300	395	515	675	800	950	650	45
	6					375				950		
	7					370				950		
	8					380				950		
	9					360				925		
	10	35	115	190	285	375	505	675	800	925	650	40
	11					350				900		
	12					360				900		
	13					355				875		
	14					[illegible]				850		
	15	30	110	180	255	[illegible]	475	625	750	850	550	30

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol [illegible]50) applied.

b E/M corporation CP-28 lubricant is a paste containing 60% molybdenum disulfide, an organic barium compound, mineral oil, and lithium grease. The CP-28 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4969 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-65. TORQUE-TENSION DATA FOR IVD CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION CP-29.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
65	1	50	170	245	315	390	470	550	650	750	430	45
	2					415				900		
	3					400				875		
	4					370				850		
	5	30	150	210	285	365	450	555	700	850	535	30
	6					360				850		
	7					350				850		
	8					360				850		
	9					335				825		
	10	35	145	260	385	360	425	550	700	850	540	35
	11					340				850		
	12					355				850		
	13					330				800		
	14					325				800		
	15	40	125	200	260	335	415	520	650	800	515	35

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-29 lubricant is a complex mixture containing molybdenum disulfide, finely divided copper metal particles, silica, and mineral oil. The CP-29 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00031 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-66. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-29.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
66	1	75	210	370	480	625	775	925	1,050	1,200	925	75
	2					650				1,300		
	3					500				1,025		
	4					470				975		
	5	35	160	260	350	445	535	675	800	950	650	30
	6					445				1,000		
	7					410				975		
	8					385				925		
	9					390				925		
	10	30	155	270	390	540	500	625	700	900	580	30
	11					350				825		
	12					365				850		
	13					370				875		
	14					365				850		
	15	30	150	265	380	500	625	750	850	1,000	675	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-29 lubricant is a complex mixture containing molybdenum disulfide, finely divided copper metal particles, silica, and mineral oil. The CP-29 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-67. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION CP-42.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
67	1	85	150	220	310	410	525	675	775	900	600	75
	2					430				1,050		
	3					390				1,075		
	4					395				1,075		
	5	65	130	210	290	395	530	725	900	1,100	825	70
	6					375				1,050		
	7					350				1,000		
	8					330				975		
	9					310				925		
	10	40	105	170	235	330	455	650	800	950	650	45
	11					330				925		
	12					330				950		
	13					345				950		
	14					340				925		
	15	35	110	180	260	340	445	575	775	950	650	35

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-42 lubricant is a paste with a synthetic polyalkylene glycol base containing a high concentration of molybdenum disulfide. The CP-42 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00031 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-68. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-42.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb) 2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
68	1	100	190	295	415	555	725	875	1,025	1,225	950	90
	2					450				1,250		
	3					400				1,150		
	4					375				1,050		
	5	30	110	195	295	390	525	725	925	1,175	900	20
	6					350				1,200		
	7					380				1,150		
	8					365				1,050		
	9					355				1,000		
	10	30	85	165	250	345	460	625	800	975	650	20
	11					335				1,000		
	12					350				975		
	13					380				975		
	14					350				950		
	15	20	80	155	235	330	460	600	775	900	540	15

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-42 lubricant is a paste with a synthetic polyalkylene glycol base containing a high concentration of molybdenum disulfide. The CP-42 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00036 in.
47FLW-820 nut: Average coating thickness – 0.00047 in.

TABLE A-69. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION FORMKOTE T-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
69	1	85	190	295	385	480	585	700	800	875	600	85
	2					550				850		
	3					575				875		
	4					600				900		
	5	90	250	400	560	700	800	850	900	975	750	110
	6					675				1,000		
	7					725				1,000		
	8					700				1,025		
	9					725				1,075		
	10	100	340	575	725	900	975	1,025	1,100	1,200	850	110
	11					750				1,100		
	12					750				1,125		
	13					775				— [d]		

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation FormkoteT-50 is a dry film lubricant containing graphite suspended in a high temperature resin binder. The Formkote T-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average plating thickness – 0.00030 in., average plating and lubricant thickness – 0.00047 in.

47FLW-820 nut: Average plating thickness – 0.00044 in., average plating and lubricant thickness – 0.00075 in.

d Since the nut was starting to bind on the bolt due to loss of lubrication, the test was terminated.

TABLE A-70. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION FORMKOTE T-50.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
70	1	90	200	315	410	510	600	725	800	900	625	105
	2					600				1,075		
	3					700				1,375	1,100 [d]	

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Formkote T-50 is a dry film lubricant containing graphite suspended in a high temperature resin binder. The Formkote T-50 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00035 in. average coating and lubricant thickness – 0.00044 in.

47FLW-820 nut: Average coating thickness – 0.00045 in. , Average coating and lubricant thickness – 0.00059 in.

d Since a high breakaway torque indicated the nut was starting to bind, test was terminated.

TABLE A-71. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION LUBRI-BOND A.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
71	1	90	225	370	515	600	675	750	850	925	650	80
	2					600				1,075		
	3					600				1,125		
	4					600				1,100		
	5	50	210	355	495	650	775	925	1,025	1,150	850	55
	6					500				900		
	7					455				850		
	8					445				825		
	9					410				800		
	10	40	125	220	320	425	530	650	750	825	550	35
	11					455				850		
	12					445				850		
	13					455				850		
	14					480				875		
	15	40	145	250	370	510	650	750	800	900	600	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Lubri-Bond A is an air drying, solid film lubricant containing molybdenum disulfide and graphite in a resin binder. The Lubri-Bond A lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00035 in., average shank diameter with lubricant – 0.4994 in., average plating and lubricant thickness – 0.00058 in.

47FLW-820 nut: Average coating thickness – 0.00042 in., Average plating and lubricant thickness – 0.00129 in.

TABLE A-72. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION LUBRI-BOND A.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
72	1	80	190	310	410	480	570	650	775	900	600	70
	2					580				1,050		
	3					650				1,125		
	4					750				1,275		
	5	33	200	380	570	800	1,000	1,150	1,250	1,475	1,225	285

Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

E/M Corporation Lubri-Bond A is an air drying, solid film lubricant containing molybdenum disulfide and graphite in a resin binder. Lubri-Bond A lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00033 in., average shank diameter with lubricant – 0.4995 in., average coating and lubricant thickness – 0.00069 in.

47FLW-820 nut: Average coating thickness – 0.00047 in., Average coating and lubricant thickness – 0.00159 in.

d Since increasing torques implied loss of lubrication, test was terminated.

TABLE A-73. TORQUE-TENSION TEST DATA FOR AN IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-42.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
73	1	100	190	295	415	555	725	875	1,025	1,225	950	90
	2					450				1,250		
	3					400				1,150		
	4					375				1,050		
	5	30	110	195	285	390	525	725	925	1,175	900	20
	6					350				1,200		
	7					380				1,150		
	8					365				1,050		
	9					355				1,000		
	10	30	85	165	250	345	460	625	800	975	650	20
	11					335				1,000		
	12					350				975		
	13					380				975		
	14					350				950		
	15	20	80	155	235	330	460	600	775	900	540	15

a The lubricant was applied to the threads of the bolt and nut.

b E/M Corporation CP-42 lubricant is a paste with a synthetic polyalkylene glycol fluid base containing a high concentration of molybdenum disulfide.

c NAS1306-10 bolt: Shank diameter – 0.4967 in., coating thickness – 0.00035 in.
47FLW-820 nut: coating thickness – 0.00037 in.

TABLE A-74. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION CP-116.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
74	1	40	120	170	250	335	445	495	570	700	420	35
	2					280				700		
	3					270				675		
	4					265				650		
	5	40	100	150	220	275	370	455	550	650	365	40
	6					275				675		
	7					280				700		
	8					280				675		
	9					275				675		
	10	38	90	145	205	265	350	425	520	625	330	38
	11					260				650		
	12					260				650		
	13					255				625		
	14					250				625		
	15	35	55	135	190	250	315	405	500	600	300	35

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-116 is a complex mixture consisting of molybdenum disulfide, mineral oil, and petrolatum. The CP-116 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00038 in.
47FLW-820 nut: Average coating thickness – 0.00046 in.

TABLE A-75. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH E/M CORPORATION CP-116.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
75	1	45	110	175	235	315	395	490	590	700	405	35
	2					260				675		
	3					260				650		
	4					270				675		
	5	40	90	140	205	270	350	440	545	650	375	35
	6					270				650		
	7					270				675		
	8					270				675		
	9					270				675		
	10	35	95	155	215	280	360	465	560	675	380	35
	11					270				675		
	12					280				675		
	13					280				675		
	14					265				650		
	15	35	90	145	205	265	345	450	545	650	330	

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-116 is a complex mixture consisting of molybdenum disulfide, mineral oil, and petrolatum. The CP-116 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00040 in.
47FLW-820 nut: Average coating thickness – 0.00039 in.

TABLE A-76. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-116.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
76	1	90	160	230	310	400	500	625	725	850	550	80
	2					390				850		
	3					370				850		
	4					345				850		
	5	45	140	215	305	400	505	650	750	850	550	40
	6					365				800		
	7					325				750		
	8					320				750		
	9					310				700		
	10	30	90	165	240	335	405	490	590	700	390	30
	11					315				700		
	12					295				700		
	13					295				675		
	14					290				650		
	15	30	80	150	210	300	365	450	540	650	345	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-116 is a complex mixture consisting of molybdenum disulfide, mineral oil, and petrolatum. The CP-116 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4984 in., average coating thickness – 0.00035 in.
47FLW-820 nut. Average coating thickness – 0.00045 in.

TABLE A-77. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-116.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
77	1	90	155	235	325	430	500	625	700	800	490	90
	2					325				700		
	3					310				700		
	4					295				675		
	5	45	95	150	210	280	350	445	535	650	375	40
	6					280				675		
	7					275				650		
	8					275				650		
	9					270				650		
	10	35	80	130	190	260	350	430	525	650	355	35
	11					260				625		
	12					250				625		
	13					250				625		
	14					255				650		
	15	30	80	135	190	260	340	435	535	650	355	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-116 is a complex mixture consisting of molybdenum disulfide, mineral oil, and petrolatum. The CP-116 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00030 in.
47FLW-820 nut: Average coating thickness – 0.00041 in.

TABLE A-78. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION CP-116.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
[illegible]	1	110	185	265	340	420	510	625	700	800	490	90
	2					350				750		
	3					330				775		
	4					330				775		
	5	50	100	165	225	310	400	500	625	750	410	50
	6					305				750		
	7					290				700		
	8					290				700		
	9					280				675		
	10	40	85	135	195	270	345	430	540	650	345	35
	11					270				675		
	12					265				650		
	13					260				650		
	14					260				650		
	15	30	80	135	190	265	355	445	560	650	355	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation CP-116 is a complex mixture consisting of molybdenum disulfide, mineral oil, and petrolatum. The CP-116 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00045 in.
47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-79. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
79	1	50	120	195	270	355	425	505	625	700	390	40
	2					350				725		
	3					350				750		
	4					345				725		
	5	30	120	195	260	320	395	480	575	700	370	30
	6					310				700		
	7					300				700		
	8					315				700		
	9					310				700		
	10	30	110	185	250	305	360	445	530	650	345	30
	11					300				700		
	12					300				700		
	13					300				700		
	14					300				700		
	15	30	105	180	245	310	400	475	555	675	360	30

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4988 in., average coating thickness – 0.00037 in.
47FLW-820 nut: Average coating thickness – 0.00044 in.

TABLE A-80. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
80	1	35	100	175	240	320	395	470	540	650	350	30
	2					310				700		
	3					330				725		
	4					340				750		
	5	30	105	180	250	320	405	480	570	700	390	30
	6					330				700		
	7					310				700		
	8					305				700		
	9					305				700		
	10	30	100	170	235	310	400	490	590	725	415	30
	11					300				725		
	12					295				700		
	13					300				700		
	14					290				675		
	15	25	80	150	200	270	350	430	530	650	345	25

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00035 in.
47FLW-820 nut: Average coating thickness – 0.00042 in.

TABLE A-81. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
81	1	45	120	210	280	360	450	555	675	750	455	40
	2					365				750		
	3					330				725		
	4					320				700		
	5	40	100	170	235	310	390	490	600	725	415	40
	6					310				725		
	7					300				725		
	8					295				725		
	9					300				725		
	10	40	90	150	215	285	360	450	560	675	385	40
	11					280				675		
	12					285				700		
	13					270				650		
	14					265				650		
	15	35	85	140	205	270	340	440	535	650	340	40

a Nut supplied with wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00032 in.
47FLW-820 nut: Average coating thickness – 0.00041 in.

TABLE A-82. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
82	1	90	180	265	350	440	540	675	750	875	570	70
	2					435				900		
	3					375				875		
	4					350				800		
	5	55	145	220	290	375	465	560	675	800	510	50
	6					360				800		
	7					335				775		
	8					320				750		
	9					315				750		
	10	40	120	190	250	320	405	510	650	750	455	40
	11					305				700		
	12					310				700		
	13					295				700		
	14					295				675		
	15	35	100	165	220	290	380	465	550	675	365	35

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4988 in., average coating thickness – 0.00037 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-83. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
83	1	85	175	280	375	450	540	650	775	875	600	80
	2					400				875		
	3					405				900		
	4					405				900		
	5	40	125	220	310	400	510	650	775	900	600	35
	6					390				875		
	7					355				825		
	8					355				800		
	9					355				800		
	10	35	100	165	245	340	430	530	650	750	420	35
	11					315				725		
	12					325				725		
	13					310				725		
	14					315				725		
	15	30	75	150	225	315	420	505	625	725	390	30

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4938 in., average coating thickness – 0.00038 in.
47FLW-820 nut: Average coating thickness – 0.00043 in.

TABLE A-84. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ARMITE LABORATORIES MIL-T-83483.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
84	1	135	240	330	420	515	625	725	800	925	675	100
	2					420				875		
	3					455				900		
	4					420				850		
	5	50	155	230	310	395	480	600	725	825	575	50
	6					365				800		
	7					370				800		
	8					370				800		
	9					360				775		
	10	40	120	190	270	350	435	535	650	750	420	40
	11					335				725		
	12					335				750		
	13					320				725		
	14					325				725		
	15	40	115	185	250	315	400	495	585	700	385	40

a Nut had wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Armite Laboratories MIL-T-83483 lubricant is a paste containing 50% molybdenum disulfide and 50% petrolatum. The MIL-T-83483 lubricant was applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4935 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00040 in.

TABLE A-85. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION FORMKOTE T-50 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
85	1	110	175	240	335	440	520	625	725	800	525	100
	2					390				800		
	3					345				750		
	4					300				750		
	5	45	115	170	235	305	395	505	625	775	490	45

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Formkote T-50 is a dry film lubricant containing graphite suspended in a high temperature resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50 percent synthetic graphite and 50 percent petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Formkote T-50 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4989 in., average coating thickness – 0.00036 in., average shank diameter with Formkote T-50 - 0.4999 in., average coating and Formkote T-50 thickness - 0.00042 in., 47FLW-820 nut: Average coating thickness – 0.00046 in., average coating and Formkote T-50 0.00048 in.

d The Formkote T-50 was removed after the first torque-tension cycle during ultrasonic cleaning.

TABLE A-86. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION PERMA-SLIK S AND FEL-PRO INCORPORATED C-601-S

Test No.[a,b,c,d]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)[d]								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
86	1	110	195	280	365	455	545	650	750	850	565	110
	2					355				800		
	3					330				800		
	4					315				800		
	5	60	110	165	255	320	425	560	675	800	520	55

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M corporation Perma Slik S is an air dried, solid film lubricant containing molybdenumdisulfide in a minimum amount of binder. Fel-Pro incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Perma-Slik S lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4988 in., average coating thickness – 0.00037 in., average shank diameter with Perma-Slik S – 0.4989 in., average coating thickness – 0.00038 in.

47FLW-820 nut: Average coating thickness – 0.00041 in., average coating and Perma-Slik S thickness – 0.00074 in.

d Perma-Slik S wore off the threads of the bolt and nut after three torque-tension cycles.

TABLE A-87. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT OVERCOATED WITH WHITFORD CORPORATION XYLAR 101 AND LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
87	1	85	185	295	365	460	570	675	775	900	625	90
	2					410				825		
	3					385				800		
	4					320				800		
	5	30	95	150	225	310	410	520	650	750	460	25

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Whitford Corporation Xylar 101 coating contains nonmetallic fillers in combination with ceramic materials to extend the performance of aluminum coatings. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Xylar 101 coating on threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4985 in., average coating thickness – 0.00053 in., average shank diameter with Xylar 101 – 0.4990 in., average coating and Xylar 101 thickness – 0.00053 in.

47FLW-820 nut: Average coating thickness – 0.00041 in., average coating and Xylar 101 thickness – 0.00060 in.

TABLE A-88. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT OVERCOATED WITH WHITFORD CORPORATION XYLAR 101 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
88	1	110	225	315	420	525	650	725	825	950	700	120
	2					445				850		
	3					360				725		
	4					315				725		
	5	40	110	170	235	310	400	510	600	700	440	45

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Whitford Corporation Xylar 101 coating contains nonmetallic fillers in combination with ceramic materials to extend the performance of aluminum coatings. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Xylar 101 coating on threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00040 in.

47FLW-820 nut: Average coating thickness – 0.00046 in., average coating and Xylar 101 thickness - 0.00067 in.

TABLE A-89. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT OVERCOATED WITH WHITFORD CORPORATION XYLAR 101 AND FOR IVD ALUMINUM-COATED NUT AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
89	1	130	175	250	330	420	520	625	700	800	525	115
	2					370				750		
	3					290				700		
	4					280				700		
	5	40	100	150	210	230	375	470	575	700	420	40

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Whitford Corporation Xylar 101 coating contains nonmetallic fillers in combination with ceramic materials to extend the performance of aluminum coatings. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Xylar 101 coating on threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4984 in., average coating thickness – 0.00033 in., average shank diameter with Xylar 101 – 0.4989 in., average coating and Xylar 101 thickness – 0.00052 in.

47FLW-820 nut: Average coating thickness – 0.00045 in.

TABLE A-90. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
90	1	60	105	160	230	310	400	470	570	700	390	55
	2					305				675		
	3					285				650		
	4					270				650		
	5	40	105	160	225	305	395	500	600	700	400	45
	6					305				700		
	7					300				700		
	8					300				700		
	9					290				700		
	10	30	85	145	215	285	370	475	590	700	420	30
	11					270				725		
	12					265				700		
	13					265				700		
	14					255				700		
	15	25	75	130	190	260	350	450	570	700	400	30

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00032 in., average shank diameter with Everlube 1346 – 0.4995 in., average coating and Everlube 1346 thickness – 0.00081 in.

47FLW-820 nut: Average coating thickness – 0.00043 in., average coating and Everlube 1346 thickness – 0.00092 in.

TABLE A-91. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
91	1	70	115	185	250	330	405	505	600	700	390	60
	2					275				625		
	3					290				650		
	4					270				650		
	5	45	95	145	205	270	360	455	560	650	365	50
	6					330				725		
	7					270				650		
	8					270				650		
	9					265				650		
	10	40	105	155	215	285	375	465	565	700	405	40
	11					265				675		
	12					270				700		
	13					265				700		
	14					270				725		
	15	35	85	130	185	260	350	450	570	725	420	35

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00033 in., average shank diameter with Everlube 1346 – 0.4998 in., average coating and Everlube 1346 thickness – 0.00073 in.

47FLW-820 nut: Average coating thickness – 0.00046 in., average coating and Everlube 1346 thickness – 0.00095 in.

TABLE A-92. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
92	1	65	115	165	245	330	425	490	560	675	370	55
	2					320				700		
	3					315				725		
	4					300				700		
	5	40	110	160	220	295	380	490	600	725	415	40
	6					310				725		
	7					270				700		
	8					265				700		
	9					270				700		
	10	35	90	145	205	275	365	470	580	700	400	35
	11					270				700		
	12					270				700		
	13					270				700		
	14					265				700		
	15	35	85	145	200	270	360	470	590	700	410	30

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4986 in., average coating thickness – 0.00031 in., average shank diameter with EM-6256 – 0.4993 in., average coating and EM-6256 thickness – 0.00072 in.

47FLW-820 nut: Average coating thickness – 0.00048 in., average coating and EM-6256 thickness – 0.00084 in.

TABLE A-93. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
93	1	55	115	175	250	330	410	490	560	650	335	50
	2					290				650		
	3					280				625		
	4					270				650		
	5	35	90	150	205	275	370	470	570	675	370	35
	6					350				750		
	7					305				700		
	8					320				750		
	9					300				750		
	10	30	85	135	200	285	390	510	625	750	455	35
	11					330				825		
	12					290				800		
	13					275				800		
	14					270				750		
	15	30	80	135	200	275	375	495	650	775	460	30

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4983 in., average coating thickness – 0.00034 in., average shank diameter with EM-6256 – 0.4987 in., average coating and EM-6256 thickness – 0.00060 in.

47FLW-820 nut: Average coating thickness – 0.00047 in., average coating and EM-6256 thickness – 0.00080 in.

TABLE A-94. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
94	1	90	140	195	250	325	405	500	600	700	405	85
	2					300				625		
	3					255				625		
	4					255				650		
	5	40	100	150	210	280	365	470	580	675	380	50
	6					335				775		
	7					325				725		
	8					285				700		
	9					275				700		
	10	35	100	155	220	290	370	475	590	700	420	35
	11					285				700		
	12					290				700		
	13					290				700		
	14					270				700		
	15	35	80	140	210	305	390	500	625	725	430	35

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544.
The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4983 in., average coating thickness – 0.00026 in., average shank diameter with EM-6286 – 0.4996 in., average coating and EM-6286 thickness – 0.00118 in.

47FLW-820 nut: Average coating thickness – 0.00047 in., average coating and EM-6286 thickness – 0.00161 in.

TABLE A-95. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
95	1	75	125	180	250	335	425	510	600	700	415	80
	2					325				700		
	3					300				725		
	4					310				725		
	5	40	110	170	235	315	410	515	625	725	445	40
	6					320				750		
	7					310				700		
	8					280				700		
	9					275				700		
	10	35	90	155	210	280	365	460	570	700	410	35
	11					280				700		
	12					270				700		
	13					280				725		
	14					295				725		
	15	35	90	150	215	290	395	515	625	725	440	35

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4982 in., average coating thickness – 0.00030 in., average shank diameter with EM-6286 – 0.4995 in., average coating and EM-6286 thickness – 0.00105 in.
47FLW-820 nut: Average coating thickness – 0.00047 in., average coating and EM-6286 thickness – 0.00112 in.

TABLE A-96. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
96	1	70	135	200	270	345	440	530	650	750	425	75
	2					320				700		
	3					330				700		
	4					315				700		
	5	30	95	165	245	320	405	505	625	725	420	30

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00034 in.
47FLW-820 nut: Average coating thickness – 0.00047 in., average coating and Everlube 1346 thickness – 0.00091 in.

TABLE A-97. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
97	1	100	165	220	290	360	450	575	650	750	510	110
	2					290				650		
	3					260				600		
	4					240				600		
	5	35	75	130	205	275	330	405	500	600	360	40

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolat formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4987 in., average coating thickness – 0.00039 in.
47FLW-820 nut. Average coating thickness – 0.00047 in., average coating and Everlube 1346 thickness – 0.00079 in.

TABLE A-98. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in. lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
98	1	70	130	190	250	320	410	510	600	700	435	80
	2					315				650		
	3					275				650		
	4					270				625		
	5	35	80	135	195	265	330	430	480	625	370	35

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt: Average shank diameter – 0.4987 in., average coating thickness – 0.00041 in.
47FLW-820 nut: Average coating thickness – 0.00040 in., average coating and EM-6256 thickness – 0.00064 in.

TABLE A-99. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E.M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
99	1	65	120	190	260	335	420	485	600	675	380	60
	2					305				600		
	3					255				580		
	4					240				565		
	5	35	80	140	180	235	300	395	485	570	315	40

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00039 in.
47FLW-820 nut. Average coating thickness – 0.00048 in., average coating and EM-6256 thickness – 0.00073 in.

TABLE A-100. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
100	1	70	110	160	225	305	370	460	540	625	370	65
	2					280				625		
	3					270				600		
	4					270				600		
	5	35	80	140	200	265	345	415	500	600	345	40

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt. Average shank diameter – 0.4986 in., average coating thickness – 0.00039 in.
47FLW-820 nut. Average coating thickness – 0.00043 in., average coating and EM-6286 thickness – 0.00128 in.

TABLE A-101. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICANT WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)								Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)									
			2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000		
101	1	110	165	220	280	335	390	475	560	675	395	110
	2					280				625		
	3					270				625		
	4					290				625		
	5	50	90	150	220	290	360	425	510	625	360	40

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet M'L-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c NAS1308-10 bolt Average shank diameter – 0.4985 in., average coating thickness – 0.00035 in.
47FLW-820 nut Average coating thickness – 0.00046 in., average coating and EM-6286 thickness – 0.00150 in.

APPENDIX B

TORQUE-TENSION DATA FOR ALC WHEEL TIE-BOLTS FINISHED WITH IVD ALUMINUM OR CADMIUM AND LUBRICATED WITH MIL-T-5544 GRAPHITE-PETROLATUM

TABLE B-1. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
1	1	185	8,100	17,770	27,530	31,520	36,340	1,550	110
	2						37,460		
	3						37,070		
	4						37,290		
	5	140	11,120	21,130	30,250	33,810	38,280	1,500	100
	6						42,150		
	7						43,190		
	8						43,920		
	9						44,560		
	10						45,110		
	11						45,530		
	12						46,970		
	13						46,840		
	14						45,100		
	15	130	12,500	24,070	34,260	39,480	44,710	1,400	100

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7486 in., average plating thickness – 0.00038 in.
47FLW-1216 nut: Average plating thickness – 0.00043 in.

TABLE B-2. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
2	1	180	10,970	23,330	33,640	38,110	42,640	1,450	160
	2						41,460		
	3						40,100		
	4						41,790		
	5	170	9,690	21,720	31,920	36,430	40,940	1,500	180
	6						43,510		
	7						42,660		
	8						43,160		
	9						42,780		
	10						44,020		
	11						45,730		
	12						44,220		
	13						43,700		
	14						42,900		
	15	150	10,780	21,170	30,740	35,600	41,430	1,450	160

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7482 in., averag[illegible]ating thickness – 0.00030 in.
47FLW-1216 nut: Average plating thickness – 0.00041 in.

TABLE B-3. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
3	1	190	9,770	20,800	30,640	34,590	39,650	1,600	165
	2						39,010		
	3						40,080		
	4						40,990		
	5	150	11,000	21,420	32,140	36,940	41,760	1,500	185
	6						42,220		
	7						40,750		
	8						42,080		
	9						41,540		
	10						42,090		
	11						43,550		
	12						42,790		
	13						42,430		
	14						43,660		
	15	150	11,050	22,040	32,440	36,380	43,230	1,450	170

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7483 in., average plating thickness – 0.00031 in.
47FLW-1216 nut: Average plating thickness – 0.00050 in.

TABLE B-4. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
4	1	270	5,920	14,650	23,480	28,000	33,030	1,600	260
	2						35,200		
	3						32,680		
	4						35,340		
	5	120	10,790	19,620	27,180	3,040	34,790	1,600	130
	6						36,410		
	7						37,140		
	8						36,130		
	9						36,920		
	10						37,170		
	11						38,370		
	12						39,780		
	13						38,760		
	14						37,820		
	15	110	14,210	23,800	31,450	35,790	39,740	1,600	120

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7484 in., average coating thickness – 0.00036 in.
47FLW-1216 nut: Average coating thickness – 0.00036 in.

TABLE B-5. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
5	1	360	4,600	14,990	24,190	28,070	32,480	1,700	315
	2						34,880		
	3						34,820		
	4						34,530		
	5	130	10,430	20,160	28,060	31,990	35,790	1,600	140
	6						35,870		
	7						35,960		
	8						36,860		
	9						37,580		
	10						37,080		
	11						36,970		
	12						37,570		
	13						36,720		
	14						37,020		
	15	90	13,650	22,520	31,540	35,150	39,210	1,550	100

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7480 in., average coating thickness – 0.00041 in.
47FLW-1216 nut: Average coating thickness – 0.00038 in.

TABLE B-6. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
6	1	320	5,340	17,420	27,580	31,940	35,890	1,500	330
	2						35,730		
	3						34,010		
	4						35,850		
	5	130	8,360	18,830	27,630	31,400	36,030	1,550	120
	6						36,990		
	7						36,280		
	8						35,650		
	9						36,740		
	10						36,290		
	11						36,260		
	12						36,360		
	13						36,640		
	14						35,800		
	15	100	11,760	20,560	28,640	31,650	35,460	1,550	100

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7482 in., average coating thickness – 0.00038 in.
47FLW-1216 nut: Average coating thickness – 0.00039 in.

TABLE B-7. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
7	1	320	7,650	18,660	28,430	32,550	38,920	1,500	220
	2						43,770		
	3						43,160		
	4						42,170		
	5	140	10,350	20,770	31,400	35,950	42,130	1,400	130
	6						43,200		
	7						44,010		
	8						45,680		
	9						46,090		
	10						45,250		
	11						42,860		
	12						42,990		
	13						43,320		
	14						43,360		
	15	100	13,290	23,590	34,190	38,920	44,470	1,400	130

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7485 in., average coating thickness – 0.00041 in.
47FLW-1216 nut: Average plating thickness – 0.00039 in.

TABLE B-8. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPCRATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
8	1	260	6,930	18,630	30,320	35,370	42,110	1,450	310
	2						43,250		
	3						42,360		
	4						43,080		
	5	160	10,250	21,750	32,130	37,650	43,360	1,450	180
	6						43,480		
	7						42,550		
	8						42,670		
	9						43,540		
	10						41,650		
	11						43,910		
	12						42,960		
	13						43,420		
	14						44,680		
	15	135	14,090	24,420	33,850	38,450	44,140	1,450	140

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7482 in., average coating thickness – 0.00039 in.
47FLW-1216 nut: Average plating thickness – 0.00039 in.

TABLE B-9. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
9	1	280	9,290	20,420	30,610	34,700	39,900	1,450	310
	2						40,750		
	3						42,090		
	4						42,140		
	5	140	10,290	20,590	31,120	35,430	40,800	1,400	190
	6						43,630		
	7						47,290		
	8						44,760		
	9						43,770		
	10						42,960		
	11						42,380		
	12						42,630		
	13						41,980		
	14						42,960		
	15	110	13,810	23,170	32,560	37,300	43,200	1,400	130

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c NAS632-18: Average shank diameter – 0.7480 in., average coating thickness – 0.00038 in.
47FLW-1216 nut: Average plating thickness – 0.00042 in.

TABLE B-10. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,300	1,500	1,800	2,100		
10	1	370	2,760	14,810	23,380	27,600	31,850	1,700	430
	2						37,630		
	3						36,590		
	4						37,040		
	5	170	12,770	22,580	30,530	34,520	38,920	1,600	190
	6						36,900		
	7						36,520		
	8						36,310		
	9						36,670		
	10						36,820		
	11						36,280		
	12						35,870		
	13						35,760		
	14						34,900		
	15	130	8,960	17,640	25,430	28,860	33,840	1,600	150

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c NAS632-18: Average shank diameter – 0.7483 in., average coating thickness – 0.00041 in.
47FLW-1216 nut: Average coating thickness – 0.00036 in., average coating and Everlube 1346 thickness – 0.00067 in.

TABLE B-11. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
11	1	340	3,050	13,170	24,470	29,200	36,840	1,600	375
	2						37,080		
	3						37,320		
	4						39,910		
	5	130	7,690	17,050	24,910	28,750	33,690	1,550	150
	6						35,950		
	7						36,310		
	8						35,510		
	9						36,040		
	10						36,700		
	11						37,480		
	12						37,010		
	13						36,890		
	14						38,670		
	15	100	10,270	21,220	29,530	33,060	37,210	1,600	100

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c NAS632-18 bolt: Average shank diameter – 0.7482 in., average coating thickness – 0.00039 in.
47FLW-1216 nut: Average coating thickness – 0.00041 in., average coating and EM-6256 thickness – 0.00081 in.

TABLE B-12. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			500	1,000	1,500	1,800	2,100		
12	1	330	5,250	16,810	27,930	32,370	40,070	1,600	320
	2						39,160		
	3						38,580		
	4						38,940		
	5	170	10,550	20,810	30,290	34,250	39,350	1,550	150
	6						39,850		
	7						39,600		
	8						38,300		
	9						39,460		
	10						39,640		
	11						39,990		
	12						39,980		
	13						40,340		
	14						39,540		
	15	120	12,510	23,890	32,160	36,470	40,640	1,500	110

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c NAS632-18 bolt: Average shank diameter – 0.7485 in., average coating thickness – 0.00042 in.
47FLW-1218 nut: Average coating thickness – 0.00044 in., average coating and EM-6286 thickness – 0.00096 in.

TABLE B-13. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
13	1	100	7,340	14,890	23,300	30,830	38,550	1,000	100
	2						35,970		
	3						33,980		
	4						33,250		
	5	80	8,050	14,530	22,340	26,010	33,410	1,025	75
	6						33,260		
	7						34,830		
	8						34,380		
	9						33,860		
	10						34,180		
	11						32,220		
	12						31,730		
	13						32,900		
	14						31,680		
	15	80	8,770	14,210	21,010	27,020	31,510	1,050	80

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6236 in., average plating thickness – 0.00040 in.
47FLW-1018 nut: Average plating thickness – 0.00037 in.

TABLE B-14. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
14	1	115	7,450	14,660	23,070	27,780	34,430	975	110
	2						32,450		
	3						32,740		
	4						33,990		
	5	80	7,900	13,810	22,100	28,370	34,310	1,000	85
	6						34,480		
	7						34,290		
	8						34,480		
	9						33,770		
	10						32,030		
	11						31,190		
	12						31,030		
	13						32,480		
	14						31,570		
	15	70	8,690	14,220	21,060	25,300	32,040	1,050	70

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6238 in., average plating thickness – 0.00044 in.
47FLW-1018 nut: Average plating thickness – 0.00038 in.

TABLE B-15. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
15	1	115	7,490	14,190	21,480	26,550	33,190	1,000	95
	2						32,660		
	3						32,920		
	4						35,040		
	5	80	8,490	14,100	22,040	28,920	34,970	1,050	80
	6						34,430		
	7						34,620		
	8						34,570		
	9						35,440		
	10						36,030		
	11						35,320		
	12						35,610		
	13						35,780		
	14						35,120		
	15	70	9,980	15,160	22,550	28,360	34,890	1,050	75

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6237 in., average plating thickness – 0.00040 in.
47FLW-1018 nut: Average plating thickness – 0.00036 in.

TABLE B-16. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
16	1	150	5,790	11,670	17,910	23,430	28,530	1,150	130
	2						26,290		
	3						28,870		
	4						28,640		
	5	70	6,200	12,260	19,800	24,770	29,520	1,050	75
	6						30,520		
	7						26,240		
	8						26,570		
	9						27,670		
	10						27,690		
	11						28,060		
	12						27,980		
	13						27,760		
	14						28,120		
	15	60	7,420	13,590	20,020	24,300	28,450	1,100	60

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6233 in., average coating thickness – 0.00036 in.
47FLW-1018 nut: Average coating thickness – 0.00034 in.

TABLE B-17. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
17	1	200	3,620	9,660	16,210	21,200	26,980	1,100	195
	2						28,400		
	3						25,570		
	4						27,400		
	5	110	6,600	13,110	19,090	23,050	27,910	1,150	100
	6						28,890		
	7						27,410		
	8						29,170		
	9						29,470		
	10						29,900		
	11						29,710		
	12						29,050		
	13						29,790		
	14						29,540		
	15	70	8,140	14,110	20,090	24,930	29,340	1,050	75

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6234 in., average coating thickness – 0.00040 in.
47FLW-1018 nut: Average coating thickness – 0.00037 in.

TABLE B-18. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
18	1	170	3,310	8,230	13,200	17,060	21,790	1,050	180
	2						23,950		
	3						29,210		
	4						30,150		
	5	70	9,200	15,170	21,100	25,230	29,250	1,100	75
	6						30,130		
	7						29,950		
	8						28,770		
	9						29,580		
	10						29,120		
	11						30,540		
	12						29,900		
	13						29,760		
	14						30,320		
	15	60	9,100	15,370	21,320	25,290	30,140	1,100	55

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6231 in., average coating thickness – 0.00038 in.
47FLW-1018 nut: Average plating thickness – 0.00036 in.

TABLE B-19. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
19	1	70	10,050	18,060	27,160	36,810	40,320	650	80
	2						37,810		
	3						37,470		
	4						38,290		
	5	60	9,640	16,330	24,380	33,110	38,140	1,050	80
	6						37,680		
	7						37,120		
	8						37,050		
	9						37,260		
	10						37,270		
	11						36,550		
	12						36,960		
	13						37,640		
	14						37,250		
	15	45	11,000	17,200	24,530	31,780	36,590	1,050	50

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6234 in., average coating thickness – 0.00035 in.
47FLW-1018 nut: Average plating thickness – 0.00040 in.

TABLE B-20. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
20	1	70	8,210	14,960	23,900	32,060	37,250	1,000	75
	2						34,640		
	3						33,490		
	4						33,630		
	5	60	9,120	14,320	21,800	29,480	34,820	1,050	60
	6						35,010		
	7						34,740		
	8						36,620		
	9						35,980		
	10						35,670		
	11						36,440		
	12						36,580		
	13						36,870		
	14						36,950		
	15	60	9,990	16,450	24,230	31,250	36,580	1,050	

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6231 in., average coating thickness – 0.00037 in.
47FLW-1018 nut: Average plating thickness – 0.00041 in.

TABLE B-21. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
21	1	120	6,910	14,450	22,390	30,980	37,070	1,100	130
	2						3,250		
	3						33,120		
	4						33,130		
	5	80	8,100	13,800	20,880	28,340	33,030	1,150	85
	6						32,410		
	7						32,580		
	8						32,760		
	9						32,030		
	10						33,060		
	11						33,810		
	12						33,760		
	13						33,490		
	14						33,630		
	15	60	9,000	14,610	21,770	29,560	33,690	1,100	65

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6236 in., average coating thickness – 0.00041 in.
47FLW-1018 nut: Average plating thickness – 0.00034 in.

TABLE B-22. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
22	1	260	3,320	11,130	18,750	26,150	31,260	1,150	220
	2						29,100		
	3						29,340		
	4						24,960		
	5	95	7,770	12,750	18,410	23,700	27,300	1,200	90
	6						26,770		
	7						28,020		
	8						29,060		
	9						28,690		
	10						28,840		
	11						28,330		
	12						27,920		
	13						28,240		
	14						27,950		
	15	60	6,810	13,010	18,570	24,480	28,400	1,200	65

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet Mil.-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt: Average shank diameter – 0.6231 in., average coating thickness – 0.00041 in.
47FLW-1018 nut: Average coating thickness – 0.00037 in., average coating and Everlube 1346 thickness – 0.00061 in.

TABLE B-23. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
23	1	180	8,370	15,340	21,700	29,360	35,960	1,150	200
	2						35,130		
	3						35,190		
	4						34,510		
	5	80	9,600	16,590	23,040	29,060	33,650	1,250	90
	6						31,830		
	7						30,890		
	8						30,250		
	9						29,710		
	10						29,630		
	11						30,820		
	12						29,880		
	13						29,720		
	14						29,200		
	15	65	9,670	16,6[illegible]	22,710	28,270	31,550	1,200	60

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt: Average shank diameter – 0.6231 in., average coating thickness – 0.00033 in.
47FLW-1018 nut: Average coating thickness – 0.00034 in., average coating and Everlube 1346 thickness – 0.00082 in.

TABLE B-24. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
24	1	190	4,690	13,010	20,880	29,810	36,100	1,100	225
	2						34,920		
	3						33,700		
	4						34,130		
	5	80	9,840	15,500	21,310	27,310	32,540	1,150	100
	6						33,620		
	7						31,090		
	8						31,780		
	9						31,800		
	10						31,570		
	11						29,930		
	12						30,130		
	13						30,420		
	14						29,520		
	15	55	10,730	16,590	22,320	28,140	30,450	1,050	65

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt. Average shank diameter – 0.6231 in., average coating thickness – 0.00040 in.
47FLW-1018 nut: Average coating thickness – 0.00036 in., average coating and EM-6256 thickness – 0.00053 in.

TABLE B-25. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
25	1	200	5,560	11,950	20,520	26,470	33,710	1,200	180
	2						29,990		
	3						29,950		
	4						32,530		
	5	85	8,540	15,040	21,180	26,840	31,580	1,200	90
	6						30,780		
	7						30,870		
	8						32,020		
	9						31,260		
	10						30,730		
	11						31,460		
	12						31,770		
	13						31,580		
	14						31,110		
	15	55	9,490	15,510	20,960	26,660	30,860	1,200	65

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt: Average shank diameter – 0.6230 in., average coating thickness – 0.00040 in.
47FLW-1018 nut: Average coating thickness – 0.00036 in., average coating and EM-6256 thickness – 0.00048 in.

TABLE B-26. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
26	1	180	5,880	13,570	21,990	29,680	31,920	1,000	200
	2						29,590		
	3						30,430		
	4						28,830		
	5	80	8,700	15,230	21,040	26,630	28,570	1,050	110
	6						28,840		
	7						29,810		
	8						29,100		
	9						29,340		
	10						27,870		
	11						27,040		
	12						27,030		
	13						27,620		
	14						26,440		
	15	75	7,020	12,860	18,620	24,430	26,290	1,100	90

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt: Average shank diameter – 0.6232 in., average coating thickness – 0.00040 in.
47FLW-1018 nut: Average coating thickness – 0.00033 in., average coating and EM-6286 thickness – 0.00065 in.

TABLE B-27. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
27	1	190	7,090	16,110	24,010	31,560	37,310	1,150	210
	2						33,230		
	3						32,920		
	4						30,440		
	5	100	8,370	13,980	19,570	25,150	29,480	1,200	85
	6						32,200		
	7						31,810		
	8						29,820		
	9						30,540		
	10						30,100		
	11						30,500		
	12						31,120		
	13						30,720		
	14						31,220		
	15	75	8,800	14,500	20,330	26,360	30,490	1,200	90

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c GY1810-36 bolt: Average shank diameter – 0.6233 in., average coating thickness – 0.00034 in.
47FLW-1018 nut: Average coating thickness – 0.00034 in., average coating and EM-6286 thickness – 0.00105 in.

TABLE B-28. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
28	1	85	9,130	15,960	23,030	30,420	36,190	1,050	80
	2						30,010		
	3						25,650		
	4						25,760		
	5	65	7,660	13,370	18,140	22,670	25,820	1,100	60
	6						25,870		
	7						26,160		
	8						26,940		
	9						26,880		
	10						27,070		
	11						26,680		
	12						28,000		
	13						27,540		
	14						27,690		
	15	25	8,450	14,230	19,650	24,590	27,080	1,150	30

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c GY1810-36 bolt. Average shank diameter – 0.6235 in., average coating thickness – 0.00036 in., average shank diameter with Everlube 1346 – 0.6244 in., average coating and Everlube 1346 thickness – 0.00057 in.
47FLW-1018 nut: Average coating thickness – 0.00031 in., average coating and Everlube 1346 thickness – 0.00066 in.

TABLE B-29. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (In.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
29	1	170	7,150	15,260	24,730	34,010	39,100	1,000	185
	2						35,820		
	3						32,920		
	4						31,080		
	5	95	8,290	14,460	20,090	25,520	29,080	1,150	100
	6						27,690		
	7						27,340		
	8						28,840		
	9						29,080		
	10						29,010		
	11						29,140		
	12						28,740		
	13						28,430		
	14						28,610		
	15	80	8,100	14,080	19,370	24,970	27,940	1,150	85

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c GY1F10-36 bolt: Average shank diameter – 0.6233 in., average coating thickness – 0.00034 in., average shank diameter with EM-6256 – 0.6237 in., average coating and EM-6256 thickness – 0.00055 in.

47FLW-1018 nut: Average coating thickness – 0.00040 in., average coating and EM-6256 thickness – 0.00051 in.

TABLE B-30. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (In.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			400	700	1,000	1,300	1,620		
30	1	130	8,120	14,930	23,480	30,880	35,460	1,050	150
	2						33,840		
	3						32,350		
	4						31,420		
	5	65	9,660	15,246	20,790	25,940	30,120	1,100	75
	6						29,390		
	7						29,390		
	8						28,490		
	9						27,830		
	10						28,450		
	11						28,230		
	12						28,340		
	13						28,560		
	14						28,000		
	15	40	9,770	15,150	20,320	25,430	28,380	1,100	50

a Nut did not have a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant. Both lubricants were applied to the threads of the bolt and nut.

c GY1810-36 bolt: Average shank diameter – 0.6233 in., average coating thickness – 0.00038 in., average shank diameter with EM-6286 – 0.6245 in., average coating and EM-6286 thickness – 0.00092 in.

47FLW-1018 nut: Average coating thickness – 0.00039 in., average coating and EM-6286 thickness – 0.00100 in.

TABLE B-31. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,560	1,860		
31	1	40	13,150	19,700	25,630	30,040	34,940	1,200	20
	2						36,540		
	3						38,120		
	4						38,420		
	5	20	13,560	19,270	26,250	33,180	39,660	1,200	20
	6						40,550		
	7						41,700		
	8						40,770		
	9						41,000		
	10						41,300		
	11						41,200		
	12						41,350		
	13						41,150		
	14						42,100		
	15	20	14,230	21,280	27,790	37,090	42,750	1,150	15

a It is not known if the nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5611 in., average coating thickness – 0.00048 in.
79502-918 nut: Average plating thickness – 0.00060 in.

TABLE B-32. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,560	1,860		
32	1	30	13,540	20,170	27,290	33,300	37,110	1,300	30
	2						37,530		
	3						39,010		
	4						40,310		
	5	20	16,220	24,200	30,560	38,420	42,750	1,050	20
	6						44,200		
	7						44,250		
	8						44,350		
	9						44,850		
	10						45,200		
	11						47,850		
	12						49,150		
	13						47,950		
	14						48,350		
	15	15	17,010	24,510	32,690	41,350	47,800	950	15

a It is not known if the nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5611 in., average coating thickness – 0.00038 in.
79502-918 nut: Average plating thickness – 0.00047 in.

TABLE B-33. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,560	1,850		
33	1	30	14,220	22,160	29,040	35,830	39,800	1,250	25
	2						39,340		
	3						39,870		
	4						40,680		
	5	15	14,900	21,530	28,370	35,940	41,260	1,200	15
	6						42,100		
	7						41,750		
	8						41,400		
	9						40,960		
	10						40,720		
	11						42,610		
	12						43,210		
	13						42,360		
	14						42,950		
	15	10	16,300	22,510	29,240	36,260	42,510	1,200	10

a It is not known if the nut had a wax lubricant,(Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5615 in., average coating thickness – 0.00072 in.
79502-918 nut: Average plating thickness – 0.00062 in.

TABLE B-34. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,560	1,850		
34	1	30	11,910	17,620	22,720	27,610	31,330	1,400	25
	2						25,040		
	3						23,540		
	4						28,150		
	5	10	11,640	17,400	21,340	25,210	28,070	1,450	10
	6						26,870		
	7						27,520		
	8						28,290		
	9						28,780		
	10						28,580		
	11						29,140		
	12						29,210		
	13						29,420		
	14						29,560		
	15	5	12,410	17,620	22,380	26,780	29,750	1,400	5

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5610 in., average coating thickness – 0.00050 in.
79502-918 nut: Average coating thickness – 0.00044 in.

TABLE B-35. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,550	1,850		
35	1	40	12,220	18,080	25,690	32,180	38,090	1,350	35
	2						33,310		
	3						30,380		
	4						32,300		
	5	15	13,110	19,310	24,050	29,440	33,680	1,400	15
	6						31,240		
	7						30,410		
	8						30,500		
	9						30,710		
	10						30,050		
	11						29,380		
	12						28,290		
	13						28,340		
	14						29,090		
	15	10	13,010	17,630	22,450	26,690	29,810	1,400	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5608 in., average coating thickness – 0.00044 in.
79502-918 nut: Average coating thickness – 0.00045 in.

TABLE B-36. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,550	1,850		
36	1	30	11,610	17,770	24,640	30,960	35,040	1,400	30
	2						30,250		
	3						27,660		
	4						30,910		
	5	15	13,200	18,740	23,800	2,849	32,260	1,400	15
	6						31,110		
	7						3,057		
	8						29,500		
	9						29,140		
	10						30,760		
	11						30,210		
	12						30,020		
	13						29,840		
	14						29,420		
	15	10	11,430	17,170	21,640	26,240	29,090	1,400	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5604 in., average coating thickness – 0.00034 in.
79502-918 nut: Average coating thickness – 0.00047 in.

TABLE B-37. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			600	900	1,200	1,560	1,850		
37	1	30	12,440	19,410	27,980	34,510	39,020	1,300	25
	2						40,120		
	3						38,870		
	4						40,620		
	5	15	14,350	19,940	28,010	34,810	40,480	1,350	10
	6						40,940		
	7						40,370		
	8						39,200		
	9						38,560		
	10						40,480		
	11						42,280		
	12						42,720		
	13						42,360		
	14						40,790		
	15	5	14,310	20,350	27,480	33,900	38,850	1,300	5

a It is not known if the nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5610 in., average coating thickness – 0.00041 in.
79502-918 nut: Average plating thickness – 0.00046 in.

TABLE B-38. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb) Bolt Load (lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			600	900	1,200	1,560	1,850		
38	1	35	12,450	19,590	27,120	34,380	40,280	1,300	40
	2						42,100		
	3						43,950		
	4						42,180		
	5	20	15,420	22,500	29,440	36,820	42,190	1,300	20
	6						41,880		
	7						41,730		
	8						43,280		
	9						42,560		
	10						42,510		
	11						42,930		
	12						41,800		
	13						42,260		
	14						41,170		
	15	15	14,950	21,600	27,730	34,600	39,840	1,250	10

a It is not known if the nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5606 in., average coating thickness – 0.00041 in.
79502-918 nut: Average plating thickness – 0.00055 in.

TABLE B-39. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			600	900	1,200	1,500	1,850		
39	1	35	13,100	20,970	27,970	34,220	40,430	1,350	30
	2						39,880		
	3						37,510		
	4						39,050		
	5	15	13,780	19,690	26,230	32,050	37,350	1,300	15
	6						37,610		
	7						37,180		
	8						37,760		
	9						38,870		
	10						39,720		
	11						38,060		
	12						38,120		
	13						37,280		
	14						37,360		
	15	10	13,060	19,080	25,770	31,640	36,880	1,300	10

a It is not known if the nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS14163-09048 bolt: Average shank diameter – 0.5607 in., average coating thickness – 0.00043 in.
72502-918 nut: Average plating thickness – 0.00042 in.

TABLE B-40. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
40	1	20	980	2,994	4,920	6,652	8,030	145	20
	2						7,287		
	3						7,976		
	4						8,011		
	5	10	2,233	4,138	5,702	6,991	8,052	145	10
	6						7,886		
	7						8,480		
	8						8,550		
	9						8,024		
	10						8,530		
	11						8,570		
	12						8,260		
	13						8,054		
	14						8,780		
	15	10	1,914	3,969	5,863	7,415	8,550	140	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3115 in., average coating thickness – 0.00040 in.
42FLW-524 nut: Average plating thickness – 0.00041 in.

TABLE B-41. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
41	1	20	1,707	3,500	5,555	7,267	8,825	145	15
	2						8,125		
	3						7,996		
	4						7,905		
	5	10	2,077	3,794	5,292	6,877	8,290	140	10
	6						8,700		
	7						8,510		
	8						8,880		
	9						8,840		
	10						9,025		
	11						8,530		
	12						8,800		
	13						8,990		
	14						8,800		
	15	10	2,261	4,317	6,177	7,520	8,770	125	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3112 in., average coating thickness – 0.00043 in.
42FLW-524 nut: Average plating thickness – 0.00040 in.

TABLE B-42. TORQUE-TENSION DATA FOR CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
42	1	20	1,735	3,806	5,423	6,912	8,340	145	20
	2						8,280		
	3						8,560		
	4						8,770		
	5	10	2,507	4,484	6,049	7,406	8,540	140	10
	6						8,890		
	7						8,640		
	8						8,890		
	9						8,850		
	10						9,100		
	11						9,060		
	12						9,420		
	13						9,350		
	14						9,150		
	15	10	2,571	4,667	6,417	7,820	8,950	125	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3113 in., average coating thickness – 0.00035 in.
42FLW-524 nut: Average plating thickness – 0.00039 in.

TABLE B-43. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
43	1	30	1,208	3,048	4,776	6,737	8,320	140	35
	2						8,500		
	3						9,250		
	4						9,640		
	5	20	1,583	3,384	5,054	6,716	8,440	140	20
	6						8,910		
	7						9,100		
	8						9,500		
	9						9,450		
	10						9,220		
	11						9,375		
	12						9,570		
	13						9,540		
	14						9,500		
	15	10	2,284	4,347	6,417	8,074	9,460	120	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3115 in., average coating thickness – 0.00038 in.
42FLW-524 nut: Average coating thickness – 0.00047 in.

TABLE B-44. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
44	1	40	1,291	3,137	4,792	6,438	7,847	130	30
	2						7,780		
	3						8,340		
	4						8,650		
	5	15	2,237	3,937	5,379	6,951	8,300	135	15
	6						8,800		
	7						8,790		
	8						8,440		
	9						8,740		
	10						8,720		
	11						8,800		
	12						8,750		
	13						8,870		
	14						8,600		
	15	10	2,089	4,018	5,704	7,151	8,500	130	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3110 in., average coating thickness – 0.00033 in.
42FLW-524 nut: Average coating thickness – 0.00048 in.

TABLE B-45. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
45	1	35	940	3,077	5,180	6,647	8,170	140	40
	2						7,704		
	3						8,165		
	4						8,400		
	5	15	1,972	3,867	5,404	6,765	7,927	150	15
	6						7,857		
	7						8,360		
	8						8,480		
	9						8,260		
	10						8,305		
	11						8,011		
	12						8,070		
	13						8,360		
	14						8,143		
	15	10	2,056	3,894	5,399	6,888	8,480	135	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3111 in., average coating thickness – 0.00033 in.
42FLW-524 nut: Average coating thickness – 0.00049 in.

TABLE B-46. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
46	1	30	1,342	3,152	4,907	6,534	8,250	140	35
	2						8,048		
	3						7,931		
	4						8,700		
	5	15	1,375	3,457	5,122	6,693	8,320	135	15
	6						8,360		
	7						8,420		
	8						8,810		
	9						8,950		
	10						9,156		
	11						9,010		
	12						9,340		
	13						9,035		
	14						9,430		
	15	10	2,037	4,376	6,327	7,994	9,270	105	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3111 in., average coating thickness – 0.00032 in.
42FLW-520 nut: Average plating thickness – 0.00045 in.

TABLE B-47. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
47	1	20	1,437	3,352	5,291	7,374	9,280	115	20
	2						9,220		
	3						9,086		
	4						8,930		
	5	10	2,053	3,987	5,736	7,157	8,890	130	10
	6						9,640		
	7						9,320		
	8						9,000		
	9						9,050		
	10						9,460		
	11						9,450		
	12						9,820		
	13						9,080		
	14						10,020		
	15	10	2,104	4,189	5,997	7,010	9,580	110	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3112 in., average coating thickness – 0.00035 in.
42FLW-520 nut: Average plating thickness – 0.00035 in.

TABLE B-48. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
46	1	30	1,394	3,356	5,449	8,632	10,271	125	25
	2						9,991		
	3						9,555		
	4						9,116		
	5	15	2,218	4,085	5,605	7,312	9,015	120	10
	6						9,034		
	7						9,273		
	8						9,468		
	9						9,676		
	10						9,596		
	11						9,524		
	12						9,882		
	13						10,178		
	14						9,978		
	15	10	2,011	4,156	5,982	8,224	10,437	120	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied to the threads of the bolt and nut.

c MS21250-05016 bolt: Average shank diameter – 0.3110 in., average coating thickness – 0.00036 in.
42FLW-520 nut: Average plating thickness – 0.00042 in.

TABLE B-49. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
49	1	25	1,438	3,291	5,123	6,686	8,316	140	25
	2						8,401		
	3						8,512		
	4						8,228		
	5	10	7,698	3,704	5,327	6,971	8,381	145	10
	6						8,638		
	7						8,940		
	8						8,859		
	9						8,718		
	10						8,759		
	11						8,965		
	12						8,807		
	13						8,886		
	14						9,349		
	15	10	2,108	3,935	5,755	7,498	8,904	140	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities.. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt. Average shank diameter – 0.3110 in., average coating thickness – 0.00032 in.
42FLW-524 nut. Average coating thickness – 0.00035 in., average coating and Everlube 1346 thickness – 0.00094 in.

TABLE B-50. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EVERLUBE 1346 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
50	1	35	832	2,780	4,427	6,178	8,069	145	35
	2						8,345		
	3						8,596		
	4						8,968		
	5	15	2,252	3,889	5,405	6,918	8,477	140	15
	6						8,611		
	7						9,264		
	8						9,072		
	9						9,261		
	10						9,153		
	11						9,535		
	12						9,430		
	13						9,475		
	14						9,575		
	15	10	1,917	3,747	5,580	7,641	9,335	130	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation Everlube 1346 is an air-cured, bonded solid film lubricant formulated with molybdenum disulfide in a resin binder specifically for high temperature applications and antiseize capabilities.. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the Everlube 1346 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt. Average shank diameter – 0.3111 in., average coating thickness – 0.00037 in.
42FLW-524 nut. Average coating thickness – 0.00034 in., average coating and Everlube 1346 thickness – 0.00104 in.

TABLE B-51. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
51	1	30	1,232	3,474	5,205	7,368	10,053	130	40
	2						9,368		
	3						8,874		
	4						9,173		
	5	10	2,225	4,131	5,835	7,491	8,875	135	15
	6						9,159		
	7						9,475		
	8						9,046		
	9						9,172		
	10						9,550		
	11						9,082		
	12						9,233		
	13						9,386		
	14						9,357		
	15	10	1,927	4,148	5,969	7,976	9,206	140	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt: Average shank diameter – 0.3113 in., average coating thickness – 0.00038 in.
42FLW-524 nut: Average coating thickness – 0.00034 in., average coating and EM-6256 thickness – 0.00057 in.

TABLE B-52. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6256 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.a,b,c	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
52	1	20	1,643	3,739	5,527	7,290	8,983	140	35
	2						8,245		
	3						8,360		
	4						8,372		
	5	10	1,289	3,347	5,053	6,658	8,047	140	10
	6						7,953		
	7						8,479		
	8						9,045		
	9						6,798		
	10						8,805		
	11						9,175		
	12						9,127		
	13						9,212		
	14						9,392		
	15	5	2,276	4,376	6,206	7,688	8,968	130	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6256 is a bonded solid film lubricant formulated with molybdenum disulfide in a resin binder to produce torque-tension characteristics similar to cadmium electroplate plus wax. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6256 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt: Average shank diameter – 0.3110 in., average coating thickness – 0.00033 in.
42FLW-524 nut: Average coating thickness – 0.00035 in., average coating and EM-6256 thickness – 0.00051 in.

TABLE B-53. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
53	1	25	1,624	3,635	5,421	7,140	9,261	130	30
	2						8,303		
	3						8,209		
	4						8,498		
	5	20	1,647	3,526	5,142	6,932	8,451	145	15
	6						8,599		
	7						8,779		
	8						8,712		
	9						8,901		
	10						9,012		
	11						9,157		
	12						9,196		
	13						9,092		
	14						8,410		
	15	5	2,529	4,588	6,456	8,164	9,557	140	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt: Average shank diameter – 0.3110 in., average coating thickness – 0.00031 in.
42FLW-524 nut: Average coating thickness – 0.00038 in., average coating and EM-6286 thickness – 0.00084 in.

TABLE B-54. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND FOR IVD ALUMINUM-COATED NUT LUBRICATED WITH E/M CORPORATION EM-6286 AND THEN BOTH PARTS LUBRICATED WITH FEL-PRO INCORPORATED C-601-S.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			50	100	150	200	250		
54	1	25	1,514	3,754	5,792	7,661	9,403	140	35
	2						8,780		
	3						8,670		
	4						9,204		
	5	10	1,913	4,143	5,873	7,590	9,098	140	15
	6						9,349		
	7						9,619		
	8						9,692		
	9						9,754		
	10						10,024		
	11						9,918		
	12						10,072		
	13						9,926		
	14						10,057		
	15	10	2,735	4,837	6,734	8,508	10,199	130	10

a Nut did not have wax lubricant (Carbowax Polyethylene Glycol 3350) applied.

b E/M Corporation EM-6286 is a bonded solid film lubricant formulated with graphite in a resin binder. Fel-Pro Incorporated C-601-S lubricant is a paste containing 50% synthetic graphite and 50% petrolatum formulated to meet MIL-T-5544. The C-601-S lubricant was applied over the EM-6286 lubricant on the threads of the nut and to the threads of the IVD aluminum-coated bolt.

c MS21250-05016 bolt: Average shank diameter – 0.3110 in., average coating thickness – 0.00032 in.
42FLW-524 nut: Average coating thickness – 0.00037 in., average coating and EM-6286 thickness – 0.00081 in.

APPENDIX C

TORQUE-TENSION DATA FOR ENGINE BOLTS FINISHED WITH I'D ALUMINUM OR DIFFUSED NICKEL-CADMIUM WITH AND WITHOUT ENGINE OIL LUBRICATION

TABLE C-1 TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
1	1	40	–	–	205	1,029	1,877	65	35
	2						1,930		
	3						2,040		
	4						2,063		
	5	20	–	337	3,50	1,420	2,507	65	20

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average plating thickness – 0.00046 in.
P&W 564706 nut: Average plating thickness – 0.00043 in.

TABLE C-2. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
2	1	20	–	277	724	1,135	1,557	65	20
	2						1,689		
	3						1,838		
	4						2,049		
	5	15	–	538	1,015	1,520	2,027	65	15

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average plating thickness – 0.00045 in.
P&W 564706 nut: Average plating thickness – 0.00051 in.

TABLE C-3. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
3	1	25	–	66	647	1,164	1,867	65	25
	2						2,079		
	3						2,174		
	4						2,421		
	5	10	–	487	1,246	1,739	2,343	60	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average plating thickness – 0.00035 in.
P&W 564706 nut: Average plating thickness – 0.00049 in.

TABLE C-4. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
4	1	10	–	573	1,185	1,863	2,632	60	10
	2						2,372		
	3						2,150		
	4						2,078		
	5	5	–	690	1,122	1,613	2,034	65	5

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average coating thickness – 0.00031 in.
P&W 564705 nut: Average coating thickness – 0.00043 in.

TABLE C-5. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
5	1	15	–	393	914	1,494	2,166	60	15
	2						1,804		
	3						1,749		
	4						1,786		
	5	10	–	580	990	1,384	1,777	65	5

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average coating thickness – 0.00044 in.
P&W 564706 nut: Average coating thickness – 0.00047 in.

TABLE C-6. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			–	25	45	65	85		
6	1	15	–	503	1,166	1,998	2,681	60	10
	2						2,094		
	3						1,858		
	4						1,824		
	5	3	–	541	987	1,431	1,827	65	2

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9209-13 bolt: Average coating thickness – 0.00036 in.
P&W 564706 nut: Average coating thickness – 0.00047 in.

TABLE C-7. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM BOLT AND CADMIUM-PLATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
7	1	25	2,707	4,254	5,731	7,118	8,411	200	20

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt: Average shank diameter – 0.2879 in., average coating thickness – 0.00027 in.
42FLW-524 nut: Average plating thickness – 0.00047 in.

TABLE C-8. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM BOLT AND CADMIUM-PLATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
8	1	20	3,239	5,145	7,153	8,784	9,993	165	25

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt. Average shank diameter – 0.2875 in., average coating thickness – 0.00032 in.
42FLW-524 nut: Average plating thickness – 0.00044 in.

TABLE C-9. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM BOLT AND CADMIUM-PLATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
9	1	20	2,811	4,583	6,175	7,687	8,869	170	20

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt: Average shank diameter – 0.2878 in., average coating thickness – 0.00029 in.
42FLW-524 nut: Average plating thickness – 0.00052 in.

TABLE C-11. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
11	1	50	1,089	2,181	3,119	4,046	4,965	250	50

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt: Average shank diameter – 0.2871 in., average coating thickness – 0.00037 in.
42FLW-524 nut: Average coating thickness – 0.00034 in.

TABLE C-12. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
12	1	50	1,127	2,031	2,892	3,752	4,581	235	50

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt. Average shank diameter – 0.2875 in., average coating thickness – 0.00039 in.
42FLW-524 nut: Average coating thickness – 0.00037 in.

TABLE C-10. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
10	1	45	1,106	2,211	3,036	3,809	4,610	220	45

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt: Average shank diameter – 0.2875 in., average coating thickness – 0.00039 in.
42FLW-524 nut: Average coating thickness – 0.00030 in.

TABLE C-13. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
13	1	20	2,343	4,075	5,597	6,960	8,408	180	25
	2						9,402		
	3						8,095		
	4						7,527		
	5	10	2,320	3,420	4,365	5,420	6,468	195	15

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2882 in., average coating thickness – 0.00038 in.
42FLW-524 nut: Average plating thickness – 0.00040 in.

TABLE C-14. TORQUE-TENSION DATA FOR A DIFFUSED NICKEL-CADMIUM-PLATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
14	1	30	2,561	4,062	5,332	6,883	8,130	185	30
	2						7,873		
	3						7,236		
	4						6,445		
	5	20	1,714	2,867	4,039	5,083	6,133	190	20

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2876 in., average coating thickness – 0.00034 in.
42FLW-524 nut: Average plating thickness – 0.00046 in.

TABLE C-15. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
15	1	25	2,337	3,825	5,082	6,167	7,079	240	30
	2						4,860		
	3						5,196		
	4						5,068		
	5	10	1,805	2,755	3,547	4,259	4,882	250	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2873 in., average coating thickness – 0.00037 in.
42FLW-524 nut: Average coating thickness – 0.00036 in.

TABLE C-16. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
16	1	40	1,175	2,381	3,204	3,908	4,647	225	40
	2						4,119		
	3						4,639		
	4						4,910		
	5	10	1,446	2,455	3,325	3,992	4,629	230	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2876 in., average coating thickness – 0.00034 in.
42FLW-524 nut: Average coating thickness – 0.00036 in.

TABLE C-17. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND IVD ALUMINUM-COATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
17	1	25	2,528	3,993	5,233	6,310	7,372	225	30
	2						4,645		
	3						4,536		
	4						4,641		
	5	15	1,462	2,446	3,237	3,982	4,605	220	10

a Nut had a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2874 in., average coating thickness – 0.00037 in.
42FLW-524 nut: Average coating thickness – 0.00041 in.

TABLE C-18. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT LUBRICATED WITH ENGINE OIL.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
18	1	15	2,624	4,024	5,145	7,381	8,785	165	20
							8,933		
							9,678		
							9,189		
	5		3,091	4,559	6,080	7,301	8,592	170	10

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b MIL-L-23699 engine oil was used as the lubricant. The engine oil was applied to the threads of the bolt and nut.
c MS9210-25 bolt: Average shank diameter – 0.2873 in., average coating thickness – 0.00042 in.
42FLW-524 nut: Average plating thickness – 0.00046 in.

TABLE C-19. TORQUE-TENSION DATA FOR IVD ALUMINUM-COATED BOLT AND CADMIUM-PLATED NUT.

Test No.[a,b,c]	Cycle No.	Running Torque (in.-lb, CW Direction)	Torque On Nut (in.-lb)					Breakaway Torque (in.-lb)	Running Torque (in.-lb, CCW Direction)
			Bolt Load (lb)						
			100	150	200	250	300		
19	1	25	2,676	4,406	5,529	6,725	7,886	190	30

a Nut was supplied with a wax lubricant (Carbowax Polyethylene Glycol 3350) applied.
b The bolt and nut were assembled dry without an engine oil lubricant.
c MS9210-25 bolt: Average shank diameter – 0.2877 in., average coating thickness – 0.00034 in.
42FLW-524 nut: Average plating thickness – 0.00039 in.